UNIVERSITY OF CANTERBURY

From red zone to green corridor: an ecological approach to remediation of the Avon/Otakaro River red zone.

Prepared for the Avon-Otakaro Network

Kathryn Bates, Nick Brewer, Raewyne Gray, Charlotte Phelps & Lee Richmond

Table of Contents

Executive Summary

Following the Christchurch earthquakes extensive residential areas along the Avon/Otakaro River were deemed uninhabitable due to various geotechnical land issues and were categorised as the ‘red zone’. Following a proposal by the Avon/Otakaro Network and working alongside our community agency Forest and Bird, we aimed to establish a viable option for an ecological corridor extending from the city to the sea. Ecological corridors provide links between formerly fragmented conservation areas and habitats with the aim of increasing biodiversity and improving ecosystem health in general. After an extensive literature review we based our methodology on established conservation principles consisting of data compilation of existing biodiversity, identifying conservation goals, reviewing existing conservation areas and selecting additional conservation areas in the planning region. Initially, we created an ArcGIS map of all existing green/reserve areas, combined with the red zone map provided by CERA to get an insight into how the corridor may work. To this we added density data on native and exotic vegetation collated from extensive physical mapping of red zone residential properties. Additionally, salinity measurements were taken in the river to attempt to establish how far salt intrudes upstream on high tides. From this data we were able to propose ecological zones which reflected historical and existing conditions of the area, as well as suggest discrete strategies for water quality remediation and habitat creation such as riparian planting and constructed wetlands. It is hoped these results have provided us with sufficient information to base our recommendations for an ecological corridor along the river red zone and beyond.

Introduction

The establishment of a sustainable ecological corridor in the residential red zone of Christchurch has been proposed by the Avon/Otakaro Network (AvON). Ecological corridors allow the free movement and dispersal of species throughout areas which have become fragmented (Hilty, Lidicker Jr & Merenlender, 2006). Resilience for ecosystems is vital to their success and is provided through barrier-free corridors as they enable avenues for flora to disperse and fauna to access food, breed and migrate. Maintaining and promoting biodiversity by establishing a corridor within an urban environment such as Christchurch is likely to aid dispersal of species by increasing habitats, but it is possible that it would also provide people with a tangible and positive benefit of post-quake recovery (Berke & Glavovic, 2012; Boojh, 2012). The urban river environment of the Avon/Otakaro has been heavily modified and degraded, with loss of many native species and introduction of countless exotic species (Roper-Lindsay, 1994), many of them becoming naturalised or invasive in the region. European settlers, desperate to emulate their English gardens in the 'wilderness', removed existing riparian vegetation such as raupo and flax, deepened river and stream channels and created weirs and dams for fishing and navigational purposes of pleasure boats (Pawson, 2000). Such modifications not only affected local Māori who valued the area for mahinga kai, but resulted in likely habitat loss for birds, invertebrates and particularly for fish by constraining and blocking their migratory passages (Eikaas & McIntosh, 2006). More recently, construction of stopbanks along the river to alleviate flooding in quake induced low-lying areas is likely to hamper dispersal even further. Our research set out to discover what conditions currently existed in the red zone in order to determine if an ecological corridor was a viable option for the area.

The process of determining how to approach the topic methodologically was informed primarily by the conservation principles outlined by Margules & Pressey (2000). Summarised, these principles are: 1) compile data of existing biodiversity, 2) identify conservation goals, 3) review existing conservation areas, and 4) select additional conservation areas. By reviewing literature we discovered that these guidelines, or variations of them, are widely adhered to by practicing ecological conservationists (Allison, 2012; Begon, Townsend, & Harper, 2006; Cabin, 2011; Hilty & Merenlender, 2006), and therefore would be a suitable basis for our research. With these main principles in mind we began our investigation of what fauna/flora currently exists in the red zone.

By physically examining the area we were able to compile a useful set of data to analyse densities of both native and exotic vegetation species and determine the reach of salinity upstream on the high tide. We also investigated vegetation and fauna native to the region – what exists in which areas and where it existed in the past. In addition, and particularly after conducting our vegetation audit of the study area, it became apparent that many exotic species of both fauna and flora would flourish if left unchecked and mechanisms for managing the spread of various potentially threatening species would need to be implemented.
Reviewing further relevant literature, and consultation with Forest and Bird representative Jen Miller, highlighted other issues for consideration, such as water quality. This lead us to consider what type of remediation could be included within an ecological corridor to improve the treatment of runoff and stormwater before it enters the river. Options for water treatment which would fit with the ecological corridor concept were reviewed. This data was intended to provide sufficient information to select additional conservation areas by expanding the area to link with existing reserves (Figure 1) and allocating zones to allow success of various species of flora and fauna under varying conditions if a more natural riparian environment existed.

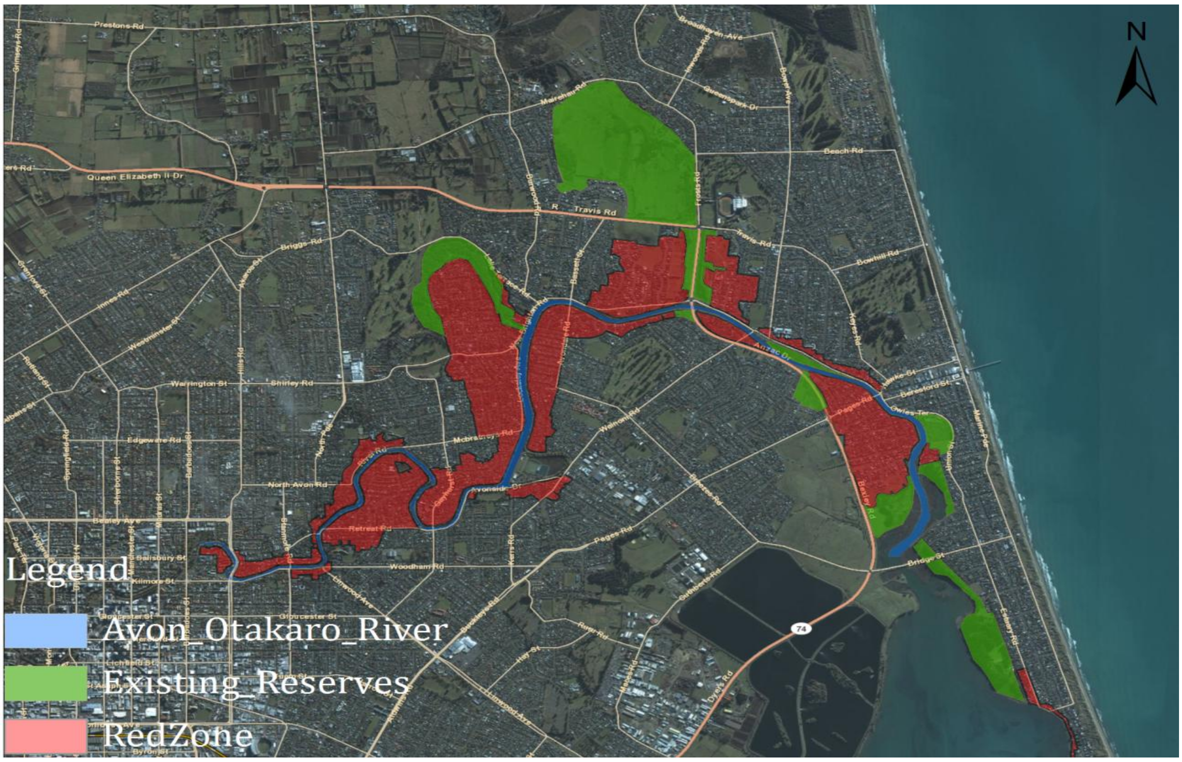

Figure 1. The Avon/Otakaro red zone which shows the fragmentation of existing reserves and how an ecological would link and substantially expand the habitat range of the area.

Literature review

Ecological corridors exist in various forms all over the world primarily to link fragmented habitats and ecosystems (Hilty & Merenlender, 2006). Many eco-corridors utilise the existing natural passage of rivers and their riparian margins, expanding their scale. A definitive example of this design within an urban environment is the Emerald Park corridor in Boston (Figure 2), known as the Emerald Necklace. This corridor is well-established and balanced in terms of catering to both the demands of nature and humans (Birge-Liberman, 2010). As Figure 2 illustrates, there are several large patches of vegetation or 'parks' running alongside the river which are loosely connected with other patches of vegetation which enable species to safely disperse, enabling them to expand as a population and providing resources such as food and shelter. There are similarities in the values of this corridor in regards to what is being proposed in the residential red zone of Christchurch. Emerald Necklace continues to improve water quality, enhance the natural habitats and implement management practices (Emerald Necklace Conservancy, 2012) – all valid approaches for consideration within the Avon/Otakaro eco-corridor which could aim to restore and maintain the current state of the area whilst also trying to recapture elements of what was there in the past.

Figure 2. The Emerald Necklace Conservancy in Boston U.S. – a prime example of a restoration of an urban waterway corridor expansion.

Compilation of data

Generally, the process of conservation planning has not been logical and new conservation zones are often located in areas that do not accurately represent the existing biodiversity (Margules & Pressey, 2000). Utilisation of red zoned areas along the Avon/Otakaro River for an ecological corridor requires extensive data to be collected on vegetation types. Plotting locations of vegetation clusters within the study area will allow similarities and differences among areas to be estimated. By employing GIS to analyse kernel density estimation and spatial autocorrelation techniques, the distribution patterns of vegetation types can be mapped and analysed, allowing for optimum recommendations using existing vegetation, retaining cultural attachments and supporting the biodiversity already present in the study area. Because of the complexity of biodiversity, time constraints and difficulty in individually recording single species, refinement was required. By classifying the observed vegetation into two subsets - native species (Figure 3), and exotic species (Figure 4) clusters - a fair representation of distribution was obtained.

Figure 3. Example of a red zone native vegetation cluster

Figure 4. Example of a red zone exotic vegetation cluster

Together both salinity and inundation contribute to a bigger picture of what may be spatially possible in ecological terms along the Avon/Otakaro. The Christchurch City Council (CCC) monitors water quality at several points on the river and conductivity (measure of salinity) is included in these tests. But beyond this, much of the literature available on the ecology of Christchurch and especially the Avon/Otakaro River, tidal reach and salinity of the river water upstream from the estuary are rarely mentioned. However, local history has shown that efforts to minimise flooding on the Heathcote/Opawaho River had drastic effects on the ecology, particularly the vegetation of that waterway, when it became clear that tidal salinity was reaching further upstream than it was prior to modification (Roper-Lindsay, 1994; Stewart, 1992). Additionally, quake damage along the Avon/Otakaro has significantly changed the dynamic of the flow of water as well changing the elevation of many areas (NIWA, 2011), leading to construction of stopbanks to control increased flood risk to surrounding residential areas. Much of this area has now been deemed uninhabitable and classified red zone. Without many of these barriers in place a natural succession would occur with inundation especially on high tides, and at a reasonably defined point upstream the water is likely to be brackish and not supportive of the vegetation that currently grows alongside the water. Predictions based on current tidal information (Figure 5) as well as the image in Figure 6 show that this is already a reality.

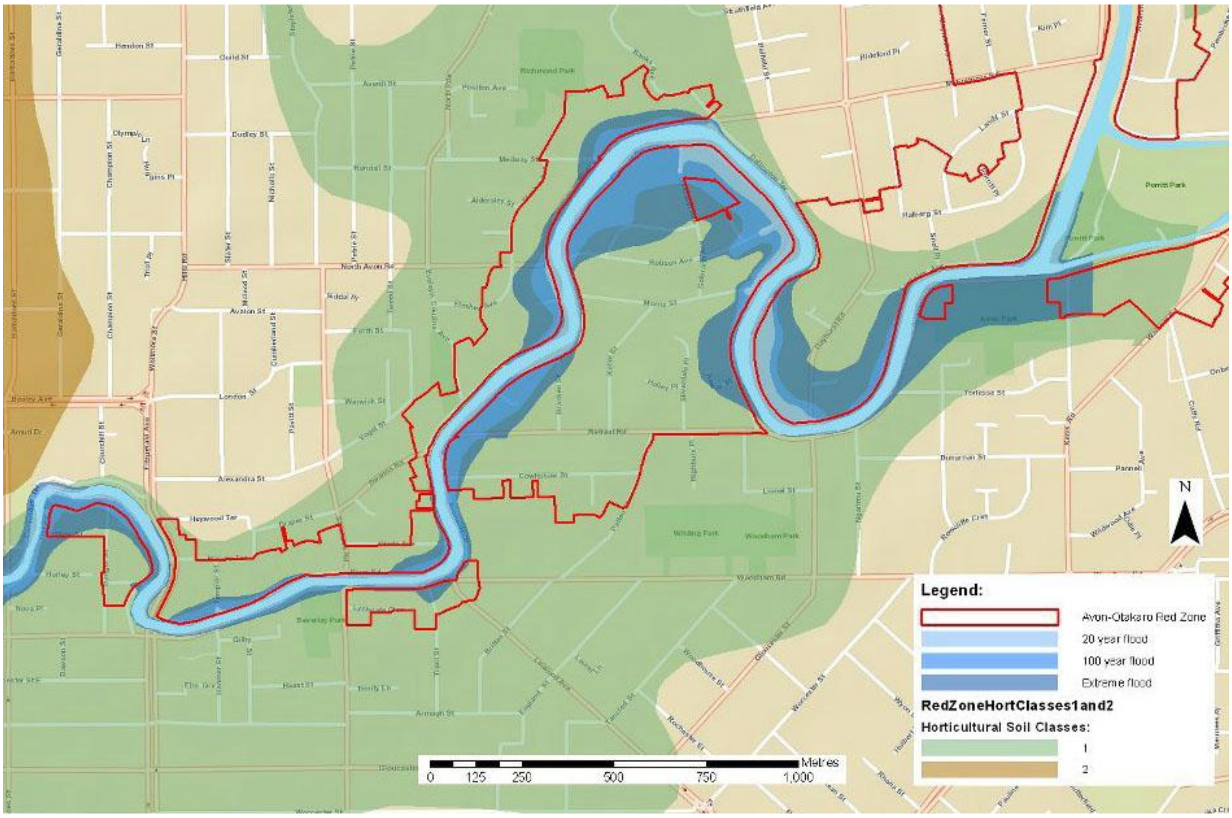

Figure 5. Predicted flood risk map of the Avon/Otakaro red zone in Christchurch.

Image courtesy Paul Goodhue

Figure 6. Example of permanent inundation or water-logging of trees in Avonside. Trees such as this exotic species were once lining the river banks, but now permanently stand in water even on a low tide.

Identifying conservation goals

Following Margules & Pressey's (2000) second principle of identifying conservation goals, establishing water quality and setting best practice targets should be prioritised for an ecological corridor bordering a metropolitan river. There are five main classes of substance that pollute waterways. Suspended solids contain contaminants and reduce light penetration (CCC, 2012), nutrients enable excessive algal growth and lower available oxygen levels especially when ‘blooms’ decay. Hydrocarbons also deplete oxygen, metals affect the health of plants and animals, and microbes are hazardous to human and animal health (CCC, 2012). Each contaminant must stay below certain ‘trigger’ values or acceptable levels for both drinking and recreational use (ANZECC, 2000). Studies by Wong, Breen, Somes & Lloyd (1999), Trowedale & Simcock (2010) and Stagge, Davis, Jamil & Kim (2012) showed that utilisation of efficient stormwater treatment systems can greatly reduce contaminants from stormwater directly entering waterways. Alongside their efficiency these methods provide the added advantage of being natural in appearance, and thus blend into an ecological reserve. The seminal Australian report by Wong et al (1999) and an in-depth publication by the CCC (2012) provide relatively broad overviews of the various mechanisms in contemporary ecologically-based wetland construction.

Maintenance of biodiversity is a vital part of nature conservation, particularly management of invasive species which have the potential to threaten the enhanced biodiversity a corridor along the Avon/Otakaro would provide. Until human settlement New Zealand’s isolation meant that very few new species managed the lengthy journey of dispersal to reach these shores (Craw, Grehan & Heads, 1999). Post-human settlement and it is a very different story with many species that have been accidentally and intentionally introduced escalating in numbers (Carlton & Ruiz, 2003), and in some cases out-competing and replacing native species (Rowe & Wilding, 2012) . As Table 1 shows the Avon/Otakaro River and nearby environs have numerous naturalised species, a number of which are classified as invasive alien species such as *Egeria densa ("Alien Species Egeria densa "),* or oxygen weed, and the fish *Scardinius erythrophthalmus* or rudd (New Zealand distribution of *Scardinius erythrophthalmus*, 2005) both of which are found in freshwater and are likely to have been introduced to waterways through aquariums. Unknown numbers of invasive species are the exotic species that are left in the gardens of the now abandoned red zone. Total elimination of invasive species is unlikely, leaving only management as the primary tool for control of this legacy (Norton, 2009).

Table1. Table of invasive species in the Christchurch area

Fauna		Flora*	
Mustela ermina	Stoat	*Ulex europaeus*	Gorse
Mustela furo	Ferret	*Cytisus scoparius*	Broom
M. Nivalis	Weasel	*Rubus fruticosus*	Blackberry
Trichosurus vulpecula	Possum	*Egeria densa*	oxygen weed
Rattus exulans	Polynesian rat/kiore	*Salix cinerea*	grey willow
Rattus rattus	Ship rat	*Didymosphenia geminata*	didymo
Rattus norvegicus	Norway rat		
Felis catus	Cat		
Canis familiaris	Dog		
Vespula germinica	German wasp		
V. Vulgaris	Common wasp		
Capra hircus	Goats		
Oryctolagus cuniculus	Rabbit		
Mus musculus	House mouse		
Erinaceus europaeus	Hedgehog		
Scardinius erythrophthalmus	rudd (Travis wetland only)		

*Basic list. Unknown species and quantities exist within red zoned gardens

Compiled from "The natural history of Canterbury" (2008)

Methods

Vegetation audit

The study area was walked in groups utilising the field maps to plot observed clusters as accurately as possible. Utilising aerial maps the outline of the study area was traced onto field maps which could be easily carried and marked, imagery and notes on predicted species were collated to allow for field classification.

After field data was collected, the cluster points were digitised onto an aerial map using GIS software as accurately as possible. Utilising a kernel density estimation tool in GIS hot spot maps for both variables were created which visually expresses distribution of variables. Integrate variables into larger clusters of 60metres to allow for statistical analysis using GIS, run a spatial autocorrelation MoransI tool to determine the distribution of both variables statistically then overlay both variables hot spot maps and generate a 3d visualisation of study area to show overall distribution.

Testing for tidally generated salinity

After some trial and error, we set three conductivity data loggers in the Avon River at 400m intervals for an extensive period (1 month) to establish any electrical conductivity (EC) change on high tides. Initially, only Odyssey Salinity/Temperature and vented Depth (pressure)/Temperature gauges were employed and placed 400m upstream from the Avondale Bridge. The first site was chosen as CCC water quality monitoring data showed that Avondale Bridge was the furthest upstream point that salinity made any impression on the baseline conductivity of the water (CCCb. At sites 2 and 3 (400m and 800m upstream respectively) CT2X data loggers were utilised to record EC and pressure changes, however as the CT2X are not corrected for atmospheric pressure changes, only pressure trends were obtainable. Once collected from the river, data were downloaded and analysed using Excel for visual representations and SPSS for statistical output.

Results

Over a period of three weeks the entire red zone study area was walked and both variables (native and exotic) were plotted. A vast amount of data was collected including 3481 native clusters and 3583 exotic. A GIS a native hot spot map was created (Figure 7) demonstrating that although vegetation was distributed throughout the study area, high density was only located in a few areas. After integrating the native points into 60 metre cluster ranges spatial autocorrelation was run to statistically represent clustering of the native variable (Figure 9). Repeating these steps for the exotic variable produced contrasting results, as shown in (Figure 8). Exotic distribution occurs in high density throughout the study area however utilising the spatial autocorrelation results it appears to be randomly distributed throughout the study area (Figure 10). Individually viewing the hot spot maps showed the overall trends, however to gain an idea of overall distribution of both variables a 3 dimensional representation was created (Figure 11), illustrating that the study area is vastly dominated by exotic vegetation. Although native vegetation occurs throughout the study area it generally appears as high density due to positive clustering (Figures 7,9).

Figure 7. Native vegetation Kernel density estimation map. Dark colour shades represent higher density locations.

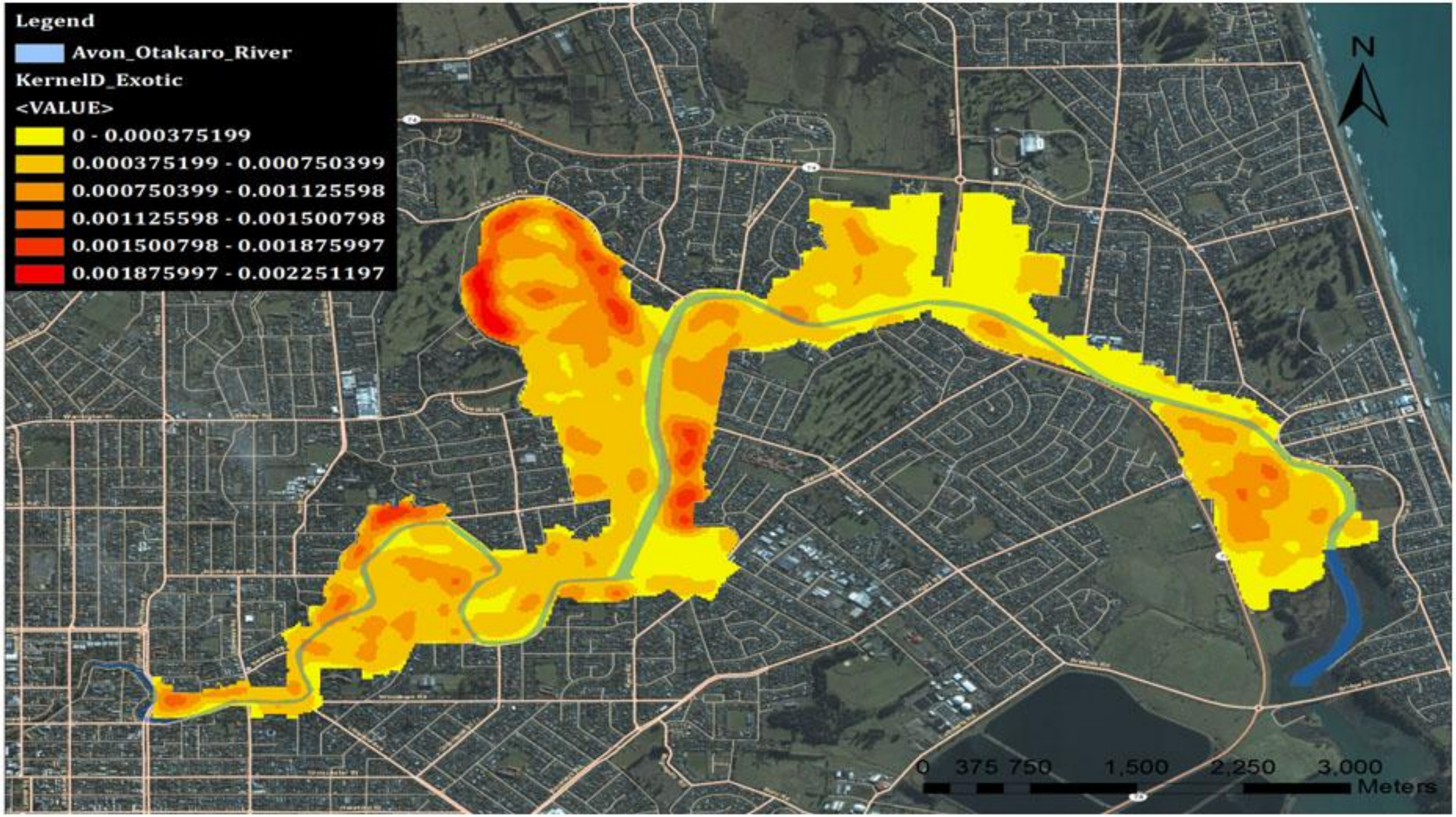

Figure 8. Exotic vegetation Kernel density estimation map. Dark colour shades represent higher density locations.

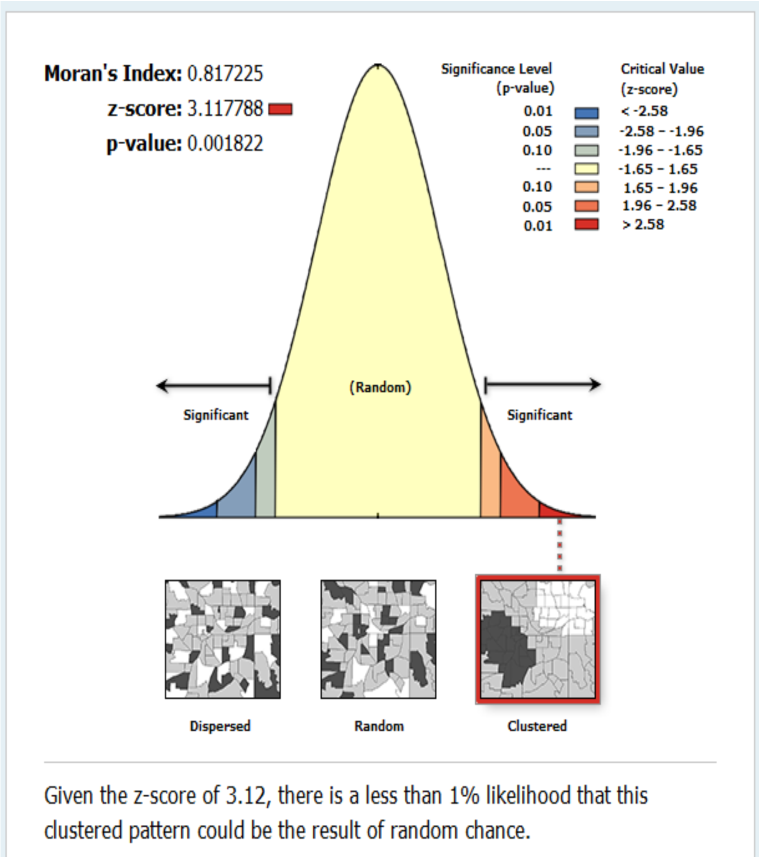

Figure 9. Spatial autocorrelation result for native variable representing random distribution.

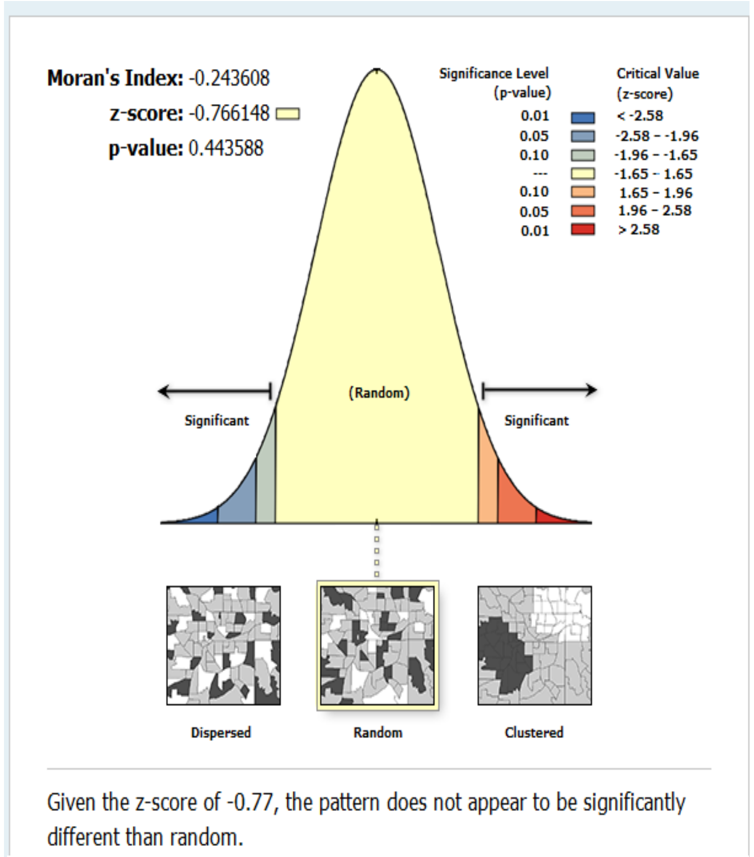

Figure 10. Spatial autocorrelation result for exotic variable representing clustered distribution.

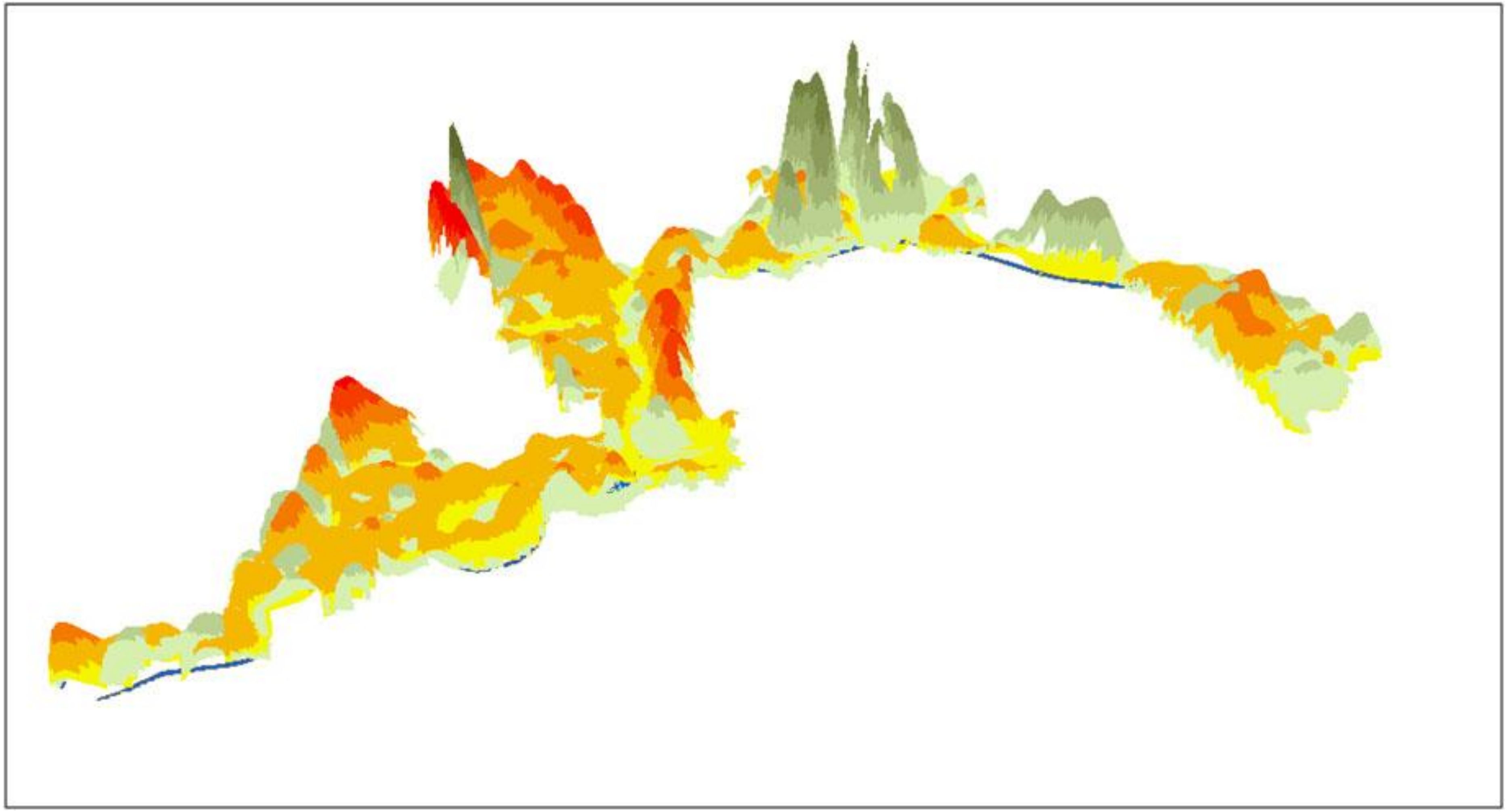

Figure 11. 3D visualisation of native and exotic variables overlaid, higher spikes represent higher density. Overall, this image shows there is a good spread of existing vegetation.

Salinity (conductivity) data was downloaded once during the month and it was found that the Odyssey salinity resolution was too incompatible to be of comparative use. Although it was left to record the entire time for safekeeping in case the two CT2X loggers happened to fail fortunately data from both CT2X showed distinct results. At site 2 there were clear delineations of salinity with the tidal range – increases on the high tides and decreases on the low tides (Figure 12), but also a period with a dip in salinity. Investigation of weather maps leads us to assume that heavy rain is responsible for this anomaly as more freshwater flow is likely to have lowered the EC. In Figure13 there appears to be little change in the salinity range with no increasing or decreasing trend on the high tide compared to site 2. This visual appraisal was substantiated with analysis with SPSS which found a significant difference in the salinity range between sites 2 and 3 (*df*=971, *P*=<0.01, *tStat*=11.01). From these data we can deduce that tidally induced salinity reaches somewhere between site 2 and site 3 or approximately 1km upstream from Avondale Bridge, or 6.5km from the estuary, on average.

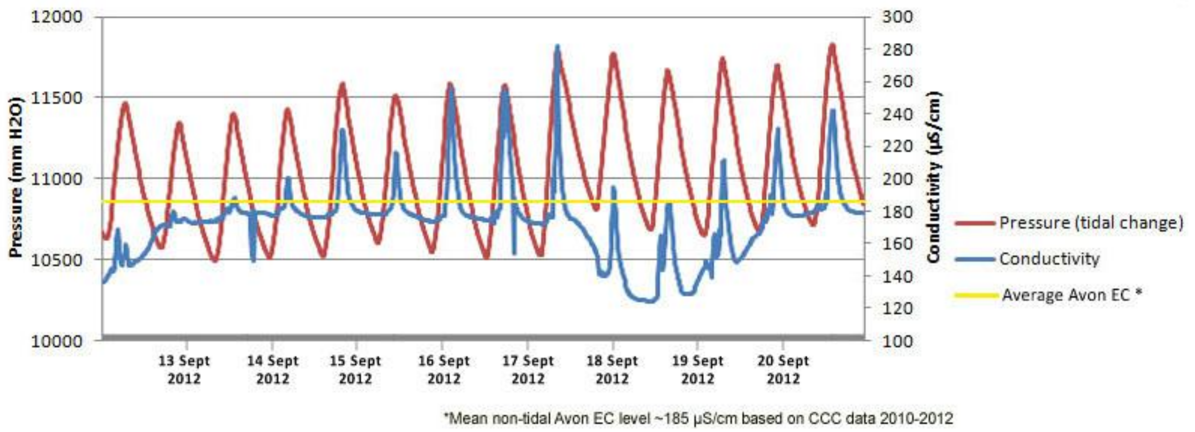

Figure 12. Site 2 salinity trend on the Avon/Otakaro River 800m upstream of Avondale Bridge

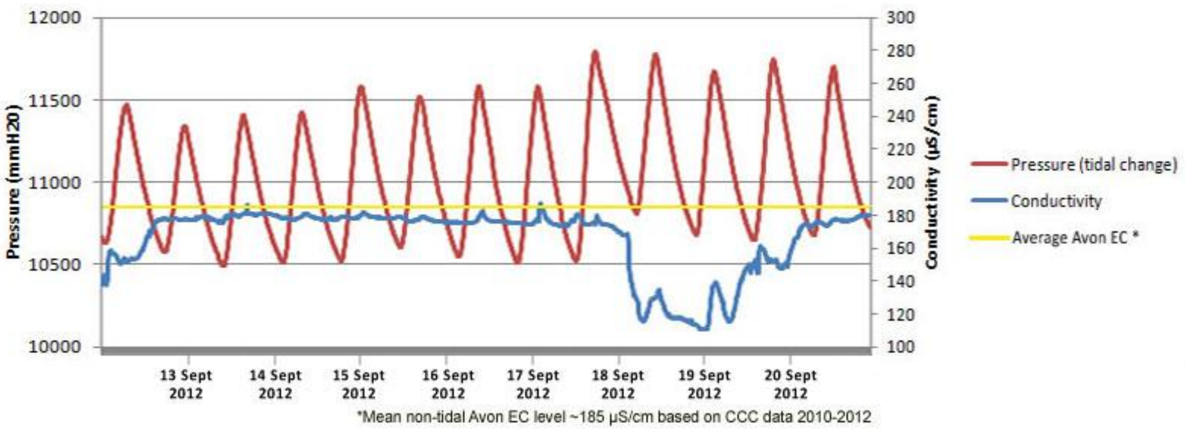

Figure 13. Site 3 salinity trend on the Avon/Otakaro River 1200m upstream of Avondale Bridge

Various options for water quality treatment exist around Christchurch (Table2) and these mechanisms have their own differing benefits and shortfalls. Research has shown best management requires a combination of, or all of the following options in unison. One of the major advantages of a large treatment area is that it requires significantly less maintenance than a smaller system. (CCCa, 2012).

Table 2. Water treatment options for improvement of urban water quality

	Macro, or gross pollutant traps	• Consist of grills or grates • Removes large litter items such as bottles and plastic bags, along with gravel in heavy flows (Wong et al, 1999). • First device used in what are termed ‘treatment trains’ (a succession of interconnecting systems). • Placed around low elevation levels • Does not have a natural appearance and Access points required for maintenance
	Grassed swales	• Used to slow peak flows down, grass filters out suspended sediment which attaches to surfaces of grass or other plants (Wong et al, 1999). • Transports flows to storage areas such as basins and wetponds. • Used where limited space allows for only one type of treatment (C.C.C., 2012), such as areas that have a slim riparian strip between the river and remaining housing.
	Soakage basin	• A planted area that allows stormwater to be filtered into groundwater • Removes phosphorous and nitrogen. • Only carries water after or during storm events (first flush*)

	Wet ponds	• Designed to trap sediments entrained during flooding events, which would otherwise be flushed directly into the catchment. • Can become over-contaminated if too small in relation to the catchment they service (Wong et al, 1999).
	Constructed wetlands	• High capacity for the removal of metals from the system as sediments settle • A latter stage in process • Natural appearance.

*First flush systems: After a period of heavy rainfall, contaminants such as heavy metals from roading are washed into the system quite quickly and later rainfall is thus a great deal cleaner, meaning that it can safely enter the catchment (Stagge et al, 2012).(Adapted from CCC, 2012)

Discussion

The 'Garden City' planting regimes of early European colonisers, who developed suburban habitats which were re-inventions of English country gardens and parks (Pawson, 2000). This meant that native species became completely dominated and out-competed by European, North American, Australian and eventually Asian and African species (Stewart, Ignatieva, Meurk, & Earl, 2004). Although not helpful for survival of endemic species, this cultural history and personal link many residents hold toward the exotic vegetation provides for an alternative view on options. Retaining these existing exotic species would allow the connections and long-standing relationships between the displaced red zone communities and environment to be maintained to some extent.

Whilst undertaking the vegetation audit initial refinement was required, this may have led to gaps in the data in areas where density made it difficult to grant a fair grade. When running the spatial autocorrelation tool there was difficulty in initially defining our integration zone of points. Keeping this in mind, the clustered and random distribution we uncovered may be slightly skewed regarding each individual's definition of what constituted a native or exotic 'cluster. However, we endeavoured to correlate our methods as accurately as possible by initially collecting as an entire group. Regardless of these specific methodological difficulties, accuracy issues have not affected the overall results and they are a fair representation of what was viewed in the field.

It is clear to see some strong trends within the vegetation audit data. These will be beneficial to effective planning strategies when striving for a viable eco-corridor that meets the aims to recommend zonal allocations. Exotic vegetation which is randomly dispersed (Figure 8) across the study area poses difficulty in creating effective planning strategies as the high density regions are generally in areas of Christchurch with enduring community history. There are very definite signs that indigenous forest can and will reappear in Christchurch, however due to cultural and aesthetic values the degree to which receptive habitats will be allowed to fully restore natural processes will be limited in specific areas (Stewart et al., 2004). A mixed exotic and native forest zone would utilise existing vegetation densities of both variables and preserve both indigenous and more recently established cultural values within it.

Furthermore, the strong patterns of clustering native vegetation (Figure 9) can be linked with proximity to existing conservation areas (Figure 14). The area located north of the Avon/Otakaro River with a high density of native vegetation (Figure 7) shares similar characteristics to that of Travis Wetland. It is therefore essential to use this existing pattern and density to minimise existing fragmentation. By utilising native wetland species the red zone directly to the south of Travis Wetland could be connected (Figure 14) indisputably increasing habitat size and ultimately enhancing biodiversity (Zipperer, Foresman, Walker, & Daniel, 2012).

Fundamental to any proposal of appropriate zones of vegetation within the corridor must be the river conditions (salinity, inundation/water-logging and tidal influence upstream) that exist currently, and in the future. The results for salinity testing during this project proved to be effective however, the study itself was in no way a rigorous scientific process, but rather a means to understand where the salt prism may reach on the high tide in order to allocate ecological zones. A longer study using more and identical types of meter, collecting data across the entire width of the river (salt water tends to 'wedge' under freshwater and would be more likely to extend further upstream in the centre of the channel) would possibly produce more accurate results. After observing the tidal flow of the river and the areas of lower elevation it is obvious that many areas will flood under not particularly extreme conditions without stop bank retention. When the area is inevitably cleared of housing the primary rationale for the stop banks will be redundant as people and property will no longer be at the same level of risk. It would seem a simple step in the restoration of the river to remove these solid structures and to provide a more natural riparian environment allowing for species dispersal and increased habitats, as well as providing more aesthetic surroundings for humans.

Our literature research showed that there are clearly defined options for aesthetically pleasing, natural-looking water treatment systems available to the designers of a riverine ecological corridor. For the effective treatment of the catchment, it would be advisable for a minimum of vegetated swales to be implemented along the banks of the Avon/Otakaro and its major tributaries both upstream and down from the corridor. One of the major inhibitions of these treatment systems is that to be successful they should be situated as close as possible to the origin of the stormwater (CCC, 2012). By the time first flushes reach swales alongside the reserve, they intermingle with later rainfall that does not contain contaminants. This is diverted into storm bypass and detention storage, which then enters the waterway.

Trowesdale & Simcock (2010) found that by only having a single system, zinc levels entering the waterway were still above recommended levels for an aquatic ecosystem. It must be stressed that even an interconnecting network of treatment systems is still not a 'miracle cure' for all pollutants. The CCC's 2012 report indicates contaminants will continue to aggregate in aquatic environments, even with best management options in place. The CCC (2012) advocates that the system has the bypass capacity for an extremely large storm event (e.g. 100 year events) as well as locating wetlands away from residential areas (to avoid such problems as mosquitoes and bird droppings). Additionally, we would recommend deterrents such as harsher penalties that would provide the incentive for people to deviate from the 'out of mind, out of sight' mentality that is prevalent in society. There must also be a strong emphasis on education involving pollutants that affect waterways, such as paint being carelessly washed down stormwater drains. Even seemingly innocuous practices such as washing a vehicle on the roadside can cause a sudden discharge of contaminants.

Creating an effective management plan that addresses such issues as water quality and the control of invasive species of fauna and flora would ensure a comprehensive guideline for the wider community to follow. Management of invasive species is an on-going issue and requires a lot of input to control, or at least keep in check. Davis & Meurk (2001) suggest weeds both compete with and cause native plant death so the management and control of them is vital. It is important to remember that if using chemicals to kill weeds that those chemicals run the risk of harming the native vegetation. Herbicide is a chemical which can be applied several ways such as spraying it onto leaves or injecting into larger invasive species. There are however many natural ways of weed control such as shading, hand weeding and mechanical weeding. Shading limits the establishment of weeds and involves limiting the light available by planting vegetation which covers them. Hand weeding which is very labour intensive is a method which is ideal for removing specific species of weeds. Mechanical weeding is a quicker method than hand weeding and removes weeds with tools such as a weedeater or a rotary slasher. A well established ecosystem provides insects such as spider mites which are natural feeders on pest vegetation. It is therefore important to consider the vegetation that is planted that would attract such species which would provide a 'free' control mechanism.

Control of invasive animals is very important as they eat native vegetation, compete with native species and ultimately change ecological processes. Similar to weed control, invasive pests can be managed both chemically and naturally. Rabbits, stoats and possums are among the many pests which have multiplied in New Zealand. Placing pellets of poison or spraying can be an effective management strategy however this runs the risk of being taken up by native species. Natural methods include shooting which guarantees the right animal is eradicated, fencing which excludes the establishment of pests in the area by blocking their entrance and bio-control which uses biological agents to control pests such as using a non-pest species to prey on or compete with the pest.

Community involvement is a necessary component of the mitigation process due to the labour intensive regime. Although many community groups exist, management of these individual groups needs to be implemented to ensure the overall effectiveness of the mitigation process. Extending from that, the education sector can be utilised by school participation through tree planting and other ecology related class programmes. This would encourage the youth of the community to foster ownership and respect for the environment and fits within the criteria for years 1-13 in the NZ National Curriculum.

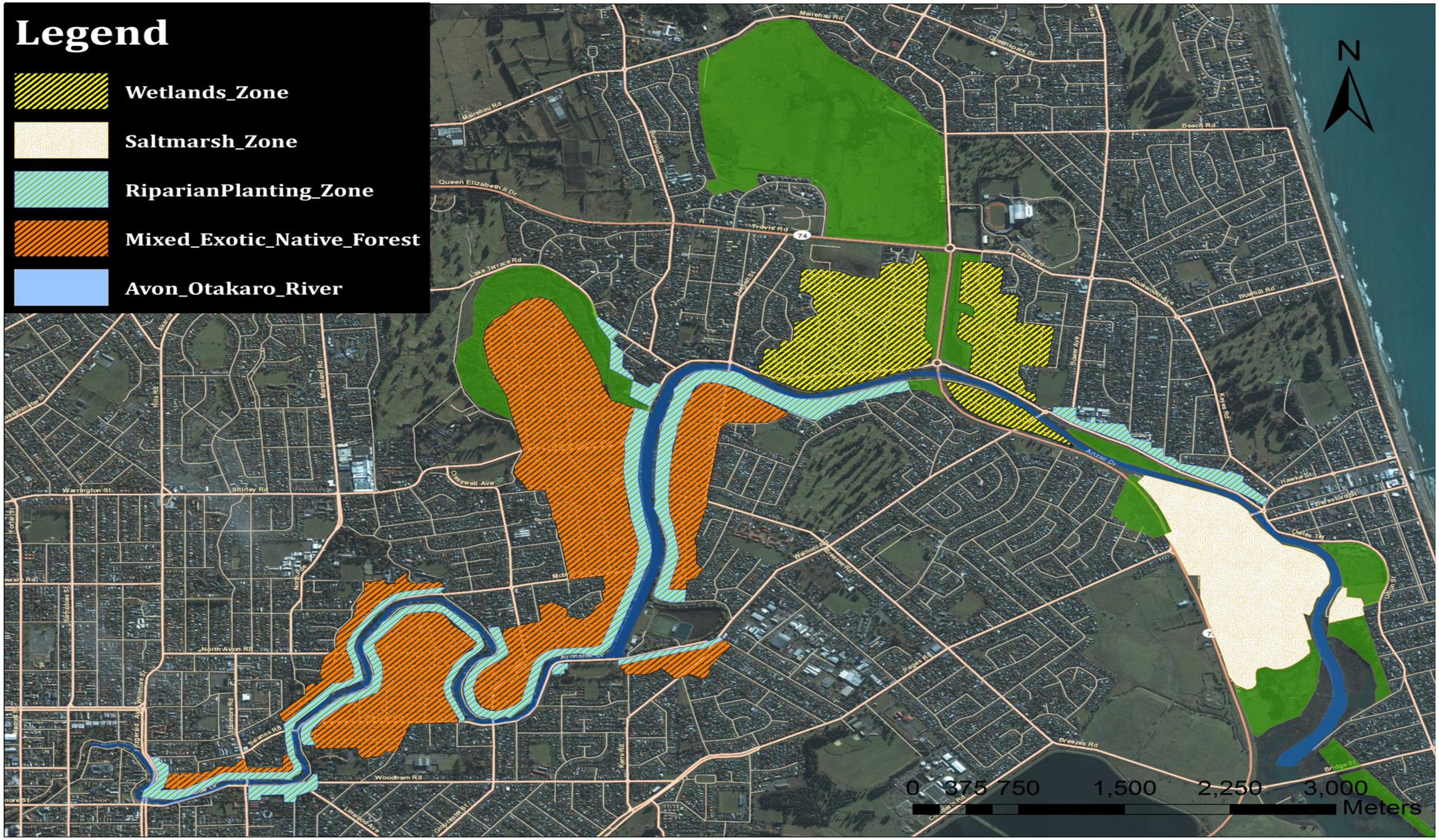

Figure 14. Existing conservation areas and recommended zonal allocation along the Avon/Otakaro River ecological corridor.

If time was not such a confining restraint, each contributing variable could have been more intensively studied than was allowable in the short time frame that Geog 309 provides. Additionally this study could have included further possible variables such as soil types, existing Avon pollutant levels, and current water table levels. Soil types would have enabled us to recommend specific vegetation species for each zone and allow us to specifically site where water treatment mechanisms could be situated. However, overall the data we have collated provides an adequate basis for further research.

Conclusions

Limited funds and lack of data often force viable recommendations to be ignored. Corridors provide benefits above and beyond the associated increase in habitat area, facilitating interpatch movement and maintaing mutualisms between plants, animals and humans.

This study provides general recommendations for zones within an expanded ecological corridor to link existing fragments, and future research. More specific areas of study need to be undertaken to make this corridor an unquestionably viable option for the Avon/Otakaro red zone. Principally, specific compilation of species of both flora and fauna are needed in order to fully understand the current and potential biodiversity in the study area; study on salt and water inundation tolerance of existing species that may be affected by naturalisation of river banks, and an empirical assessment of tidal influence on freshwater reaches of the river; continued monitoring if water quality and sediment testing for contaminants; a comprehensive study into where water treatment options would be most beneficial to the river water quality as well as stop bank removal and remediation of the riverbank; and an in-depth assessment of the extent of conservation that is required (enclosed sanctuary, recreational park, for instance) – what can be achieved and how will different options be accepted by the local community.

Our study included no social data as that was not the focus of this report, but alongside these recommendations we suggest that strong community collaboration is fostered from the earliest possible stage to allow people the opportunity for input into an area that has obvious historical, but more importantly, sentimental value for many. All to often the environment gets overlooked in times of recovery and when it is included it is often as a token gesture rather than as full integration of ecosystem service planning. Community inclusion and collaboration, especially the education sector, from the initial stages of any plan will undoubtedly reinforce support for it as well as cultivate a strong sense of guardianship/kaitiakitanga for the area.

If the Avon/Otakaro ecological corridor plan were to be implemented it would be unique in terms of community resilience as people came to be aware and understand the importance of the natural environment as a basis for recovery, not as an afterthought or sideline.

Manaaki whenua. Manaaki tangata. Haere whakamua.

Care for the land. Care for people. Going forward.

Acknowledgements

Jen Miller Forest & Bird; Avon/Otakaro Network; Claire Kain; Zoe Dewson CCC; Prof Angus McIntosh; Paul Goodhue; Justin Harrison; Nick Key; John Skilton Travis Wetland Reserve; Avon River Rowing Clubs; And the residents of the red zone, who were more than welcoming to our presence...

References

Alien Species Egeria densa Retrieved 4 September 2012, from http://www.issg.org/database/species/search.asp?sts=sss&st=sss&fr=1&x=25&y=15&sn=egeria+densa&rn=New+Zealand&hci=-1&ei=167&lang=EN

Allison, S. K. K. (2012). *Ecological Restoration and Environmental Change: Renewing Damaged Ecosystems*: Routledge.

ANZECC (2000). Australian and New Zealand Environment and Conservation Council, Agriculture and Resource Management Council of Australia and New Zealand, guidelines for fresh and marine water quality (ANZECC) - The guidelines. *National water quality management strategy 4, 1*.

Begon, M., Townsend, C. R., & Harper, J. L. (2006). *Ecology: from individuals to ecosystems*: Wiley-Blackwell.

Berke, P. R., & Glavovic, B. C. (2012). Ecosystems and Disaster Resiliency: Contributions to a Holistic Theory of Recovery. *International Journal of Mass Emergencies and Disasters, 30*(2).

Birge-Liberman, P. (2010). (Re) Greening the City: Urban Park Restoration as a Spatial Fix. *Geography Compass, 4*(9), 1392-1407.

Boojh, R. (2012). Ecological Approach for Post-Disaster Recovery and Mitigating Future Risk *Ecosystem Approach to Disaster Risk Reduction* (pp. 187-195).

Cabin, R. J. (2011). *Intelligent Tinkering, Bridging the Gap between Science and Practice*: Island Press.

Carlton, J., & Ruiz, G. M. (2003). *Invasive species: vectors and management strategies*: Island Press.

Christchurch City Council (2012a). Waterway quality Lower Avon River Excel spreadsheet. In Z. Dewson (Ed.).

Christchurch City Council (2012b). Waterways, Wetlands and Drainage Guide — Ko Te Anga Whakaora mo- Nga- Arawai Re-po. *Part B: Design*.

Craw, R. C., Grehan, J. R., & Heads, M. J. (1999). *Panbiogeography: tracking the history of life*: Oxford University Press, USA.

Davis, M. A., & Slobodkin, L. B. (2004). The science and values of restoration ecology. *Restoration Ecology, 12*(1), 1-3.

Eikaas, H. S., & McIntosh, A. R. (2006). Habitat loss through disruption of constrained dispersal networks. *Ecological Applications, 16*(3), 987-998.

Emerald Necklace Conservancy (2012). Retrieved 5 October 2012, from http://www.emeraldnecklace.org/

Hilty, J., Lidicker Jr, W. Z., & Merenlender, A. (2006). *Corridor ecology: the science and practice of linking landscapes for biodiversity conservation*: Island Press.

Margules, C. R., & Pressey, R. L. (2000). Systematic conservation planning. *Nature, 405*(6783), 243-253.

New Zealand distribution of *Scardinius erythrophthalmus* (2005). Retrieved 4 September 2012, from http://www.issg.org/database/species/reference_files/scaery/scaery.pdf

NIWA (2011). Mapping earthquake induced topographical change and liquefaction in the Avon-Heathcote Estuary. Retrieved 9 August 2012, from http://ecan.govt.nz/publications/Reports/eq-effects-estuary-topography-liquefaction-niwa.pdf

Norton, D. A. (2009). Species invasions and the limits to restoration: learning from the New Zealand experience. *Science, 325*(5940), 569-571.

Pawson, E. (2000). Confronting Nature. In J. Cookson & G. Dunstall (Eds.), *Southern capital, Christchurch: towards a city biography, 1850-2000*: Canterbury University Press.

Roper-Lindsay, J. (1994). *Tales of the riverbank- examples of bank restoration on urban rivers*.

Rowe, D. K., & Wilding, T. (2012). Risk assessment model for the introduction of non-native freshwater fish into New Zealand. *Journal of Applied Ichthyology, 28*(4), 582–589.

Stagge, J. H., Davis, A. P., Jamil, E., & Kim, H. (2012). Performance of grass swales for improving water quality from highway runoff. *Water Research*.

Stewart, D. P. C. (1992). Reclamation of saline-sodic soils adjacent to the Heathcote River, Christchurch. *New Zealand. Natural Sciences, 19*, 45-52.

Stewart, G. H., Ignatieva, M. E., Meurk, C. D., & Earl, R. D. (2004). The re-emergence of indigenous forest in an urban environment, Christchurch, New Zealand. *Urban Forestry & Urban Greening, 2*(3), 149-158.

Trowsdale, S. A., & Simcock, R. (2011). Urban stormwater treatment using bioretention. *Journal of Hydrology, 397*(3), 167-174.

Winterbourne, M., Knox, G., Burrows, C., & Marsden, I. (Eds.). (2008). *The natural history of Canterbury*: Canterbury University Press.

Wong, T. H. F., Breen, P. F., Somes, N. L. G., & Lloyd, S. D. (1999). *Managing urban stormwater using constructed wetlands*: Cooperative Research Centre for Catchment Hydrology.

Yamada, T., Logsdon, S. D., Tomer, M. D., & Burkart, M. R. (2007). Groundwater nitrate following installation of a vegetated riparian buffer. *Science of the Total Environment*, *385*(1), 297-309.

Zipperer, W. C., Foresman, T. W., Walker, S. P., & Daniel, C. T. (2012). Ecological consequences of fragmentation and deforestation in an urban landscape: a case study. *Urban Ecosystems*, 1-12.