Road edge-effects on ecosystems

A review of international and New Zealand literature, an assessment method for New Zealand roads, and recommended actions

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An important note for the reader

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Abbreviations and acronyms

AADT	average annual daily traffic
ALAN	artificial light at night
BACI	Before–After Control–Impact
CMA	calcium magnesium acetate
dB	decibels
DOC	Department of Conservation
GIS	geographic information system
$L_{Aeq(24h)}$	time-averaged A-weighted sound pressure level over 24 hours, measured in dB
LCDB	Land Cover Database
LINZ	Land Information New Zealand
NGO	non-governmental organisation
NO_x	nitrogen oxides
NZPCN	New Zealand Plant Conservation Network
PAN-NZ	Protected Areas Network – New Zealand
PM_{10}	particulate matter 10 micrometres or less in diameter
QEII	Queen Elizabeth II National Trust
RAMM	Road Assessment and Maintenance Management
SEA	Significant Ecological Area
SNA	Significant Natural Area
SO_x	sulphur oxides
TEC	Threatened Environment Classification

Contents

Executive summary

This research was carried out in 2020 and 2021 to help Waka Kotahi NZ Transport Agency identify, assess, monitor and manage road edge-effects on biodiversity. It was a response to government directives, including the National Environmental Standards for Freshwater (including wetland protection) and in preparation for the National Policy Statement for Indigenous Biodiversity. A key objective of the research was to enable more consistent prediction, assessment and management of the edge-effects of new and existing roads on New Zealand ecosystems. This project summarises effects on terrestrial ecology, using wetlands as an interface between water and land, but excluding effects on watercourses.

Literature review

The substantial published overseas literature on road edge-effects was reviewed alongside the extremely limited New Zealand research. In this project we included all impacts of roads on biodiversity as road edge-effects because (a) impacts are measured to some degree away from the road surface and (b) a ‘road’ itself is defined as the running surface and ‘road envelope’ or ‘clear zone’ where vegetation and drainage is intensively controlled, as well as wider areas directly impacted during construction (eg, by stripping vegetation and soils). Road edge-effects were grouped into seven categories:

1. noise and vibration
2. artificial light at night (ALAN)
3. road runoff (including stormwater volumes, flows and contaminants, and gross pollutants such as litter)
4. air emissions (particulates, including metals, micro-plastics, and oxides of nitrogen, carbon and sulphur)
5. hydrological effects (including effects on groundwater, soil drainage and soil moisture)
6. habitat modification (including pest plants), fragmentation and impacts of road users
7. roadkill (unsuccessful crossing of roads by fauna).

Analysis of New Zealand road environments

We analysed New Zealand roads and features of New Zealand’s unique ecology to identify where they were similar to or different from those overseas, how these influence the scale and type of road edge-effects, and ultimately, what edge-effects ‘matter’ most in the New Zealand context. Because data on the significance of road edge-effects on most New Zealand ecosystems and species are severely limited, we used a precautionary approach that identified a wide range of potential effects alongside moderating or amplifying features. These are summarised in checklists and infographics.

Alongside the literature review, we analysed national databases to identify native-dominated land covers, New Zealand highways, and where road edge-effects were likely to be most positive or negative. Databases included the Protected Areas Network – New Zealand (PAN-NZ) database, as the impact of road edge-effects on biodiversity values is, in part, strongly influenced by the sensitivity of adjacent environments. The PAN-NZ database identifies areas primarily managed for conservation by the Crown, by territorial authorities, or by individuals through Queen Elizabeth II National Trust (QEII) conservation covenants. The Land Cover Database (LCDB) version 5.0 was used to identify wetlands and dominant vegetation at the 0.5 to 1 ha scale. The Threatened Environment Classification (TEC) database was used to identify where even small, degraded remnants and regenerating ecosystems along roads are likely to have disproportionate ecological value because they are all that is left. Road edge pressures were derived from data held by Land Information New Zealand and Waka Kotahi on vehicle numbers, noise contours and locations of streetlights, bridges and culverts. Maps were generated to show where roads intersect with particularly ecologically sensitive or ecologically depauperate areas. These maps were used to develop infographics that illustrate how:

- highway traffic volumes and road density vary across New Zealand
- highway corridors may act as refuges in landscape where little native habitat remains
- negative road edge-effects on biodiversity are greatest where highways go through conservation areas, or along coasts and wetlands.

A method for assessing road edge-effects

We developed a four-step method for assessing road edge-effects using data sources available in New Zealand. A desktop analysis of the national databases (described above) was supplemented with regional information and field assessments. This method was tested on parts of state highways via two contrasting case studies. The State Highway 16 and State Highway 18 (SH16/18) case study has dual-lane, separated highways, road runoff treated in wetlands, and extensive buffer plantings of native species. These state highways carry 30,000–60,000 vehicles/day through urbanising outskirts of north-west Auckland. In contrast, State Highway 73 (SH73) through the Waimakariri Basin is a narrow state highway with no formal stormwater treatment carrying up to 5,000 vehicles/day through both agricultural landscapes and conservation lands, including Arthur’s Pass National Park.

Results

Literature review

Roads and other linear infrastructure are ubiquitous; the roading physical footprint increases as new and upgraded roads are built and vehicle numbers increase. The area impacted by roads is initially strongly linked to the construction footprint from which soils and plants are removed. However, effects such as noise, artificial light, and impacts of stormwater discharges are disproportionately larger than the construction footprint, and effects may ripple out for hundreds to thousands of metres. The main road edge-effects on animal populations are reduced habitat quality (due to noise, light, changes in plant structure and species related to hydrological changes and weeds, and removal of tree canopy in forested areas) and reduced connectivity. New ‘edge ecosystems’ are created that tolerate high exposure and/or disturbance from roadside maintenance. Both habitat and connectivity effects influence roadkill, and can be permanent and amplify over time. The magnitude of edge-effects depends on the pressures exerted (eg, noise, stormwater runoff), which are influenced by road and vehicle characteristics. The size of edge-effects also depends on characteristics of the ecosystems and species in the wider landscape. In general, the impacts of roads through natural areas with high biodiversity values and high intactness (low fragmentation) are overwhelmingly and consistently negative. However, in areas where little habitat remains, roadside habitat can support native ecosystems. For example, dense roadside vegetation in some farmed areas supports weka and kiwi (although it can also potentially increase their vulnerability). In intensively farmed areas of Europe and North America, road verges are hotspots of flowers and pollinators, with some roadsides managed to benefit these, and other, invertebrates.

While the road pressures identified in international literature apply in New Zealand, key ecological responses to these pressures are likely to differ due to New Zealand’s extreme endemism (plants and animals only naturally found here) and their unique vulnerabilities to pressures that limit their abundance and competitiveness. The point at which effects management is required to avoid or mitigate a moderate level of adverse road edge-effects is unknown for most native New Zealand ecosystems or species. New Zealand native animals are primarily limited by predation from mammals in remaining large, contiguous natural areas, but are limited by lack of habitat in most lowland areas due to native forest clearance and wetland drainage for agriculture. Most common native birds can fly across gaps less than ~100 m, suggesting impacts of most roads on connectivity may be less important than they are internationally. However, New Zealand also has threatened populations of birds vulnerable to roadkill due to their:

- willingness to cross roads
- unwillingness (or inability) to fly
- freeze behaviour when faced by cars
- nocturnal (night) or crepuscular (twilight) activity
- slow breeding rates (eg, kiwi, kororā/little blue penguins, pāteke/brown teal and weka).

Another road pressure is traffic noise, but there are no data on the impacts of traffic noise on New Zealand land birds.

New Zealand has many ecosystems vulnerable to weed invasion and a non-native, self-established flora that continues to expand in number and area. Most road edge environments are very different from the humid, shaded, native forest ‘core’ that dominated New Zealand before deforestation, and to which many forest-dwelling native invertebrates and plants are adapted. New Zealand roadsides have a high proportion of non-native plants. This reflects low tolerance of most native species to frequent disturbance, and the presence of a few roadside weeds that are very aggressive and habitat-transforming. In some cases, seed production of these weeds is enhanced by preferential pollination by non-native invertebrates. The future biodiversity liability incurred by new weeds establishing from roadsides into areas of high ecological value is therefore substantial.

Analysis of New Zealand road environments

The centreline of over 2,000 km of state highway is within 100 m of land managed by the Department of Conservation, QEII covenant holders, or regional councils. State highways pass within 50 m of wetlands along 163 linear kilometres of road. These may include engineered wetlands for stormwater treatment or wetlands induced by linear infrastructure, but neither are able to be differentiated using available databases. Such conservation land and wetlands are likely to have higher biodiversity values, with a variable vulnerability to road edge-effects. For example, New Zealand literature suggests effects on microclimates linked to vulnerable forest flora such as bryophytes (mosses and lichens) occur 20–100 m from pasture edges, with 40–50 m considered an ‘average’.

The vast majority of New Zealand state highways receive low numbers of vehicles by international standards – less than 5,000 vehicles/day average annual daily traffic (AADT). This reduces road edge-effects linked to stormwater contaminants, air emissions and noise, which are strongly correlated with traffic volumes. Modelled noise (as time-averaged decibels (dB) over 24 hours) indicates noise levels exceeding 55–59 dB on average at 25–50 m from the centreline of rural state highways and at 200–300 m for state highways exceeding 50,000 AADT. Applying a 100 m road edge-effect buffer from all road centrelines shows 32% of the Auckland region and 5–11% of all other regions (excepting West Coast) could be impacted by some road edge-effects.

A method for assessing edge-effects

We used national and regional data to map general road edge pressures and pressure points in two case studies. Field assessments were needed to identify road edge-effects caused by pressures from pest plants/weeds and roadside maintenance, including stormwater runoff. Field assessments were also needed to identify values of small areas in depauperate landscapes with potential to act as biodiversity nodes or corridors, and to confirm whether wetlands were natural, induced, or created to treat road stormwater runoff.

The two case studies showed the largest and most disparate edge-effects were generated by four factors: habitat modification/fragmentation, stormwater, noise, and light. Roadkill was unable to be assessed.

New roads (5–15 years old) had larger overall edge-effects than old roads, due to more extensive cut/fills and greater impervious areas, which together impact soils, hydrology and stormwater runoff. Adverse edge-effects along new SH73 sections were exacerbated by the absence of coarse wood in forested areas and non-native plants. Along SH16/18, adverse effects of stormwater discharges were mitigated using constructed wetlands, and these, with extensive native plantings, increased potential habitat. However, most of these areas and adjacent estuaries were subject to ALAN and noise levels above 55 dB. Both case studies showed how changes in management of adjacent land influenced the extent, and reversibility, of edge-effects. Because road corridors are narrow and linear, vegetation management by adjacent land managers influences weed, light and noise edge-effect pressures. Land management also influences native plant and animal populations in road reserves directly and indirectly. For example, on SH73, removal of pest pines from adjacent land reduced pressures within the road corridor and triggered control within the road corridor.

Conclusions and recommendations

New Zealand land transport projects likely underestimate the size of the road-affected zone, the long-term effects of road edges, and the cumulative effects of road density. A range of effects management strategies that reduce the cumulative adverse effects of stormwater runoff (especially from high-volume roads and on high-quality receiving environments) and pest plants are proven. However, monitoring and interventions that reduce the spread of pest plants onto and along roads, and from roads into adjacent high-value environments, will require changes to maintenance contracts that also consider the impacts of agrichemicals.

The method developed to assess road edge-effects should be applied at early stages of capital projects. Priorities for ‘avoidance’ include avoiding:

- building roads through wetlands or remnants in depauperate areas
- new ALAN in ‘dark’ areas and within habitats or flight paths of vulnerable species
- new roads through areas managed for conservation
- direct stormwater discharges to surface waters.

Avoidance techniques use bridges, tunnels and retaining walls to reduce road footprints, and barriers to reduce clear zones. Anecdotal evidence suggests exclusion fencing and underpasses have helped avoid roadkill of kororā near Punakaiki. In contrast, work to avoid the introduction and spread of weeds in general, particularly within ‘striking distance’ of sensitive ecological areas, has been less effective. The increase in weed diversity and density along roads through New Zealand’s natural areas needs to be mitigated and prevented.

The road edge-effects assessment method developed for this project helps identify areas of New Zealand where road corridors could enhance native habitat by:

- increasing the quality of remnant habitats in areas where little remains (eg, using buffers to reduce effects from disturbance, noise, light, hydrology/stormwater, grazing, and weeds)
- increasing areas of habitats for common birds and insects that are mobile
- reducing roadkill and/or other mortality to levels that have no population effects.

The method was limited, however, by lack of data on construction footprints, so it will underestimate the impact. To rectify this data limitation, all capital projects should report the width and area of impervious surface to the outer edge of the road seal, the ‘construction zone’ width from which original vegetation and soils are stripped or filled (ie, re-contoured surfaces), and the clear zone managed by herbicide, pruning or mowing.

Roads and road corridors have effects on biodiversity that extend from the trafficked surfaces, through verges and drains managed by roading authorities, and into adjacent landscapes. The pressures created by roads and traffic are generally well-characterised internationally, but very little New Zealand evidence identifies how far most effects extend from roads (other than some vegetation changes) and what road-related effects create a barrier for many species. New Zealand has unique, highly endemic fauna and flora that are likely to respond differently to road pressures, particularly noise, light, stormwater runoff, disturbance and fragmentation. Fundamental research is critical to quantify the effects of road-derived noise and artificial light on a range of native birds and other fauna most likely to be affected (ie, nocturnal fauna, some forest and wetland birds) and quantify the size of the 'road-effect zone' within which adverse road impacts extend into surrounding landscapes. At the same time, studies are needed to identify where roadkill may threaten nationally vulnerable species. This information is needed to inform development and testing of avoidance, minimisation, mitigation and compensation strategies that work for New Zealand fauna and flora – for example, by embedding alternative designs into capital projects. The current knowledge gaps on effects of roads on New Zealand species and environments may be delivering effects management methods that are ineffective and represent lost opportunities to invest in actions that contribute to Waka Kotahi commitments on biodiversity. New Zealand roads efficiently and safely transport people and goods; they could also reduce harm from road edge-effects on our unique native biodiversity. In specific areas, roads could enhance native biodiversity to deliver a net positive impact.

Abstract

Roads and other linear infrastructure are ubiquitous; their footprint increases as new roads are built, roads are upgraded, and vehicle numbers increase. The environmental effects of roads are disproportionate to their footprint. Some effects ripple out for hundreds to thousands of metres, are permanent, and amplify over time. This study helps Waka Kotahi NZ Transport Agency identify, assess and manage these road edge-effects on biodiversity.

The substantial overseas literature was reviewed alongside an analysis of New Zealand road environments and features of New Zealand's unique ecology that influence the scale and type of effects. All roads generate traffic noise, stormwater runoff, and artificial light at night. The impacts of roads through natural areas with high biodiversity values and high intactness are overwhelmingly and consistently negative. However, in areas where little habitat remains, roadside habitat can support native biodiversity. These benefits and their key determinants need to be quantified in detailed studies of key taxa, especially native birds, to derive relevant, practical knowledge of road edge-effects (particularly noise, light and roadkill) and their effective mitigation (particularly reducing roadkill and using buffers). In contrast, mitigation methods that limit the spread and impacts of roadside weeds into high-value ecosystems and reduce impacts of stormwater runoff are well established.

To assess road edge-effects, we developed a four-step method that uses desktop analysis of national databases supplemented with regional information, checklists, and rapid field assessment. Testing in Auckland and Canterbury (2020/2021) showed that while desktop mapping of general road edge pressures and pressure points is efficient, field assessments are needed to assess pest plants, stormwater and values of small remnants. New research is critical to quantify the distance road edge-effects extend into surrounding landscapes. Roads need to transport people and goods efficiently and safely, but New Zealand roads can also be better at reducing and mitigating harm to New Zealand's unique biodiversity.

1 Introduction and literature review

1.1 Introduction

This project reviews the ecological effects of edges ('edge effects') created by constructing and operating linear transport, primarily roads. This project was funded to help Waka Kotahi NZ Transport Agency identify, assess, monitor and manage road edge-effects on biodiversity associated with new and existing roads in response to government directives, including the National Environmental Standards for Freshwater (including wetland protection) and in preparation for the National Policy Statement for Indigenous Biodiversity. A key objective was to enable more consistent prediction, assessment and management of edge-effects of new and existing roads on New Zealand ecosystems. This project summarises effects on terrestrial ecology, including wetlands as the interface between water and land, but excluding effects on watercourses and the marine environment.

1.1.1 Methods

The project had three parts:

- a literature review and analysis of New Zealand road environment using interrogation of national roading and environmental databases (section 1)
- development of a method to assess edge effects (section 2)
- testing of the method on two highway case studies (sections 3 and 4).

Section 5 summarises the key findings and details recommendations for monitoring, mitigation and research to underpin roading infrastructure that is measurably and significantly better than current practice at reducing overall harm from road edge-effects to native biodiversity. Key objectives were to identify beneficial effects of roads on biodiversity that could be expanded or enhanced, adverse effects causing the greatest harm that could be reduced, and areas where effects are unknown due to lack of information. Each section was designed to be relatively stand-alone. Footnotes are used throughout to identify key information sources, especially where they are open-source and web-accessible, providing a short-cut that complements the list of references.

The project was supported by a steering group and peer reviewers. The steering group provided input through meetings at the beginning of the project, when the draft literature review was delivered, before the draft road edge-effects assessment method was applied to the case studies, and after the draft report was delivered. Peer reviewers provided detailed comments on drafts of the report.

1.1.2 Outputs

The project has the following outputs:

1. Literature review with national maps (section 1).
2. Draft road edge-effects assessment method (section 2) with checklists of edge-effects (section 2.1).
3. Twelve proposed indicators for reporting road edge-effects nationally and/or by capital projects, approaches that avoid road edge-effects, and a summary of practices to mitigate negative edge-effects and enhance positive edge effects (section 5.3).
4. Monitoring, evaluation and research needed to improve certainty related to specific road edge-effects. Many of these reflected New Zealand's extreme endemism of flora and fauna, and their unique vulnerability to pressures that limit their abundance (section 5.3).

5. Seven infographics identifying spatial distribution of road edge-effects across New Zealand (Appendix A, Figures A.1 to A.4), vulnerabilities of some New Zealand native birds to roadkill (Figures A.5 to A.6) and interactions of fauna with road edges (Figure A.7).

1.2 Literature review

A literature review was used to identify and categorise road edge-effects. Particular emphasis was placed on effects likely to be influenced by New Zealand's unique ecology. Results were used to create checklists for road edge-effects (section 2.1.2), which identify features that moderate, or enhance, the severity or scale of edge-effect. Results were also used to identify actions and opportunities to enhance positive effects and/or avoid or mitigate negative road edge-effects (section 5.3). Because data on the significance of ecological effects on many New Zealand ecosystems and species is severely limited, a precautionary approach was used that identified a wide range of potential edge-effects. Data and research to improve certainty related to specific road edge-effects on New Zealand species and ecosystems were identified; these are presented as recommendations in section 5.3.

1.2.1 Method

Five scientists with field and research expertise covering native New Zealand birds, pest mammals, pest plants, wetlands and restoration ecology independently reviewed international and national journal papers, reports and books on road edge-effects in their area of expertise. The abundance of international literature is indicated by the time each researcher spent (50 to 90 hours). The literature focused on the following six questions.

- What road edge-effects are identified in international literature?
- What is the evidence for road edge-effects in New Zealand literature?
- What are differences between New Zealand and international road edge-effects, and why?
- What road edge-effects are important in New Zealand?
- What options could avoid or mitigate these effects?
- What knowledge gaps on New Zealand road edge-effects or mitigation need to be resolved?

This section summarises key findings of the literature review, focusing on application of overseas findings to New Zealand. Footnotes are included for references that are both web-accessible and useful for enthusiastic readers wanting to delve deeper.

1.2.2 Identifying and categorising road edge-effects

This project reviewed all impacts of roads on biodiversity that are measured away from the road surface. A 'road' includes the running surface, shoulders and adjacent margins, which together form prescribed 'clear zones'. Standard clear zones along highways extend 9 m from road edges. These must be maintained free of non-frangible vegetation (ie, plants that form a trunk at maturity that is more than 100 mm diameter at 400 mm height above the ground) and flax. Specifications are detailed in the *State Highway Geometric Design Manual* (NZ Transport Agency, 2000[1]) and *Guide to Road Design Part 3: Geometric Design* (AusRoads, 2021[2]) and illustrated in *Landscape Guidelines* (NZ Transport Agency, 2014a[3]; see Figure 1.1 below). This means infringing plants in these areas are pruned, slashed, mown, or sprayed with

[1] https://www.nzta.govt.nz/roads-and-rail/highways-information-portal/technical-disciplines/safety-and-geometric-design/geometric-design/

[2] https://austroads.com.au/safety-and-design/road-design/guide-to-road-design

[3] https://www.nzta.govt.nz/resources/nzta-landscape-guidelines/

agrichemicals as required, using either targeted or 'blanket' treatments, which can be extensive enough in forested landscapes to influence fragmentation edge-effects. The severity of fragmentation is also strongly linked to the road 'construction envelope' – the area that is stripped of vegetation and soils during construction. On dissected landforms this area can be hundreds of metres wide where large cut and fill batters are present, and it creates road edge-effects that persist for decades after revegetation.

Within the clear zone, some areas are even more intensively managed. Defined areas along road margins (such as around edge marker posts, signs and barriers, and along drainage channels) are required to be maintained 'vegetation-free' or near vegetation-free Figure 1.2). These areas are typically managed using mowing and/or herbicide applications that are frequent enough to maintain a distinctive, generally non-native vegetation that influences road edge-effects such as roadkill (as shown in Appendix A, Figure A.7). The interactions between road construction and road maintenance envelopes and road edge-effects are why this study uses a broader definition of effects than Forman and Deblinger (2000), who define road edge-effects as 'the area over which significant ecological effects extend outward from roads'. Forman et al. (2003) then categorised road edge-effects into six categories. In this report, we added roadkill as a seventh category, and fragmentation is included within habitat modification along with the impacts of road users and road neighbours. These seven categories of road edge-effects are used throughout this report, forming the core of the road edge-effects assessment method (section 2) and recommendations for their avoidance, mitigation, or enhancement (section 5). The seven categories are:

1. noise and vibration
2. artificial light at night (ALAN) from streetlights and vehicles, including reflected light on road surfaces
3. road runoff, including stormwater volumes, flows and contaminants, and gross pollutants (eg, litter, tyre crumbs)
4. air emissions (particulates, including metals, micro-plastics, and oxides of nitrogen, carbon and sulphur)
5. hydrological effects, including effects on groundwater, soil drainage and soil moisture
6. habitat modification (physical trimming, pest plants and effects linked to hydrology, heat and ALAN), landscape effects such as fragmentation, and impacts of road users and neighbouring land management
7. roadkill (unsuccessful crossing of roads and impacts of roadkill on adjacent areas).

Figure 1.1 **The requirement to maintain ‘clear zones’ along state highways prevents trees more than 100 mm trunk diameter at 400 mm height and flax within ~9 m from the edge of seal (top graphic) or overhanging below 6 m height. Clear zones can be narrower if barriers are present (lower graphic) and in areas with high ecological values (reprinted from NZ Transport Agency, 2014a, p. 64).**

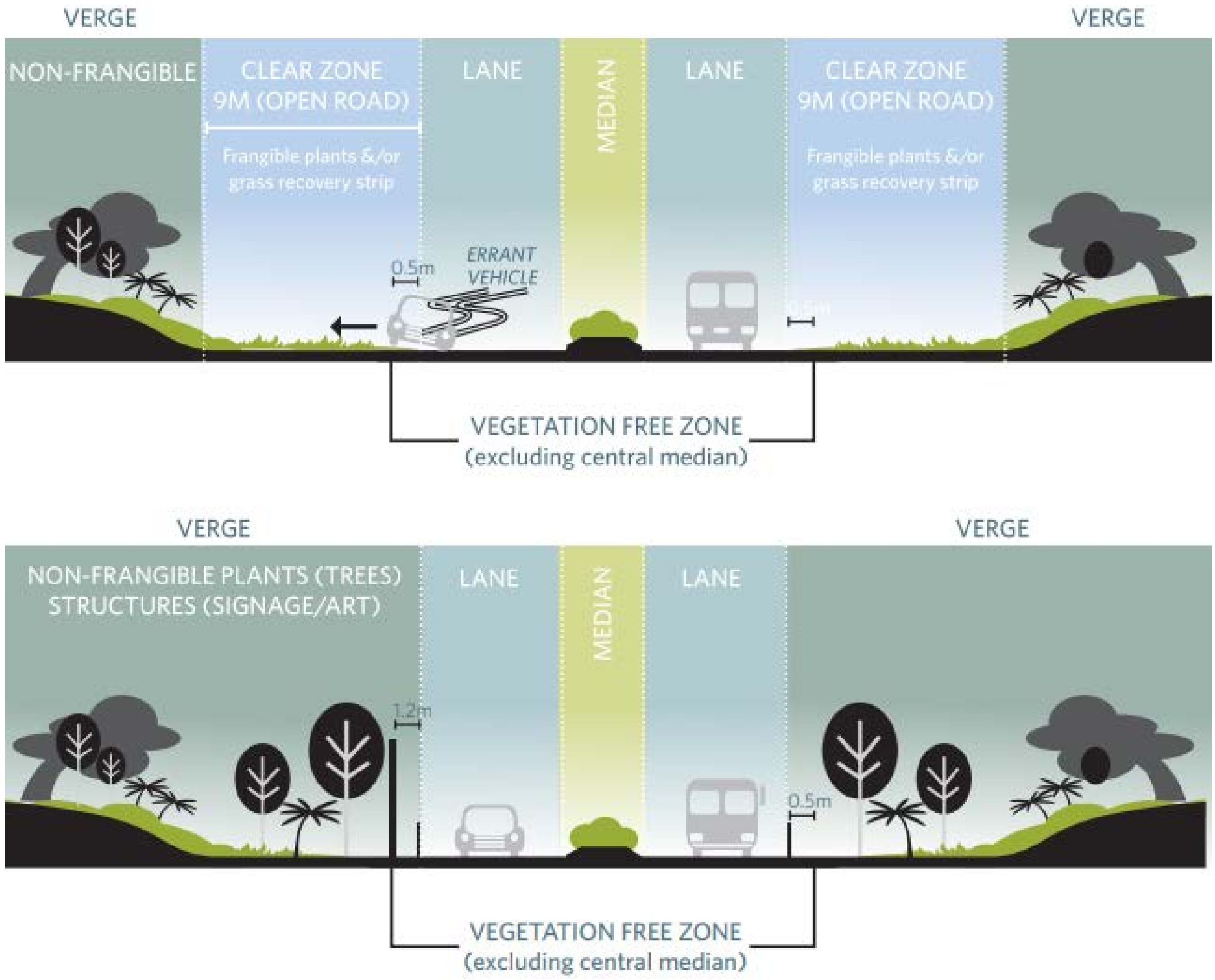

Figure 1.2 **Intensive vegetation control in a strip along the road shoulder and around each edge marker post is specified in Transit New Zealand’s *Specification for Vegetation Control* (reprinted from Transit New Zealand, 1997, p. 15).**

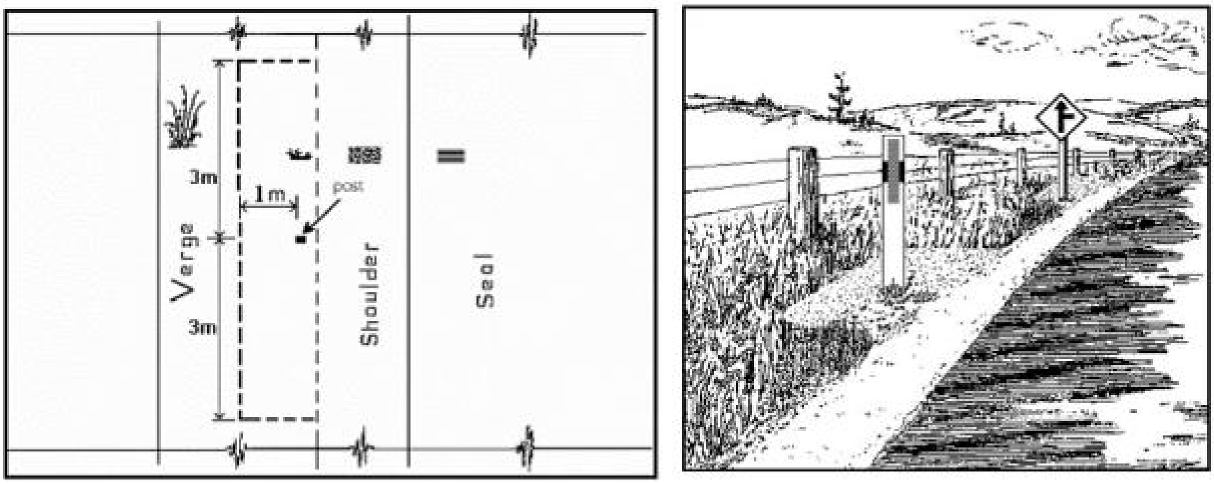

Figure 1.3 White arrows mark the edge of the intensively mown zone, and the brown arrows mark the edge of the less intensively managed 'clear zone' with frangible plants.

While international literature identifies road edge pressures, the size of the 'road-effect zone' (Forman & Deblinger, 2000; van der Ree et al., 2015) is not known for native New Zealand animals, with the possible exception of bats and petrels. There has been very little New Zealand research on the effects of roads on fauna. The last comprehensive review was in 1998 (Spellerberg & Morrison, 1998[4]) and there has been no significant New Zealand public-good science funded research to investigate the effects of roads, including edge effects. Almost no New Zealand data are available to understand adverse effects on native fauna from ubiquitous road effects such as light and noise, or for the habitat gaps created by roads through large continuous native ecosystems. Such continuous ecosystems are found where highways pass through national parks and other protected areas (see Figure A.3 in Appendix A), predominantly on the West Coast of the South Island. Habitat gaps, evidenced by New Zealand roadkill records, are also created where roads separate smaller continuous ecosystems (notably wetland birds such as pūkeko and pāteke) or breeding and feeding grounds (notably kororā/little blue penguins). The ability of New Zealand birds to cross undesirable habitat gaps such as roads varies greatly (Burge et al., 2017[5]), and there is little reliable information available about most bird species' movements in New Zealand to help inform assessments of effects. No published data indicate if, or where, roads affect native forest or wetland bird population densities, and consequently whether roads generate population-level effects.

1.2.3 Overview of road edge-effects on biodiversity

Roads are ubiquitous; their length and footprint are increasing across New Zealand. In New Zealand, roads pass through nearly every ecosystem and national park (see Figure A.3 in Appendix A). Characteristic features of roads are their narrow, continuous form with a very high proportion of edges (compared to core) that support ecosystems that are distinctive compared with adjacent land. While many of these

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[4] https://www.doc.govt.nz/globalassets/documents/science-and-technical/sfc084.pdf

[5] An Appendix summarising data for individual forest-dwelling birds is available at https://www.pfhb.nz/assets/Image-Gallery/Burge-et-al-2017-Habitat-availability-for-native-NZ-bird-species-within-the-Cape-to-City-footprint.pdf

characteristics are shared with watercourses and linear infrastructure such as railways, canals and transmission lines,[6] road edge-effects are much greater and more diverse. Road edge-effects are greater because roads have a much greater landscape density, are impervious, sometimes have streetlights, and always carry people and vehicles, which themselves exert specific noise, light, contaminant and physical disturbance pressures.

Road ecology is a relatively young area of research. Although Stoner (1925) reported roadkill over 316 miles in Iowa in his 1925 *Science* article ‘The Toll of the Automobile’, comprehensive reports on road edge-effects have only appeared in the last 25 years – for example, Sherwood et al.’s (2002) *Wildlife and Roads* papers and Forman et al.’s (2003) seminal syntheses *Road Ecology: Science and Solutions*.[7] Since then, a huge body of research has developed from North America, Australia,[8] the United Kingdom and Europe – notably the Netherlands. This research and practice informed the second core road ecology resource, *Handbook of Road Ecology* (van der Ree et al., 2015), while recent topic-specific meta-reviews summarise effects of roads on birds (Cooke et al., 2020), invertebrates (Dean et al., 2019; Jakobsson et al., 2018; Muñoz et al., 2015), and small animals (Andrews et al., 2015). This international research consistently concludes that the effects of roads on biodiversity are generally negative, particularly in natural areas with high intactness and low fragmentation – that is, in areas with high biodiversity values. Road edge-effects are amplified because many are permanent. Further, the overall influence of roads and transport infrastructure on habitat values and land use by biodiversity is probably underestimated for four reasons:

- Many effects at an individual road-scale are cumulative – for example, build-up of contaminants from vehicles (exhaust, tyre and brake emissions) and maintenance (herbicides), effects of changes in hydrology, and increasing traffic volumes.
- Effects of multiple roads are cumulative at a landscape level as new roads are built, and old roads are not removed. This exacerbates loss of unimpacted ‘core’ areas and ecosystem fragmentation effects.
- Some adverse effects are delayed (Figure 1.4) – for example, fragmentation effects that prevent recolonisation of residual habitats by fauna (meaning fragmented populations may be extinguished over time), and increase in weeds after disturbance. Weeds generally increase over time as opportunities occur for them to establish into the road corridor from adjacent landscapes, spread along the road corridor, and spread from road corridors into adjacent areas.
- Road effects on groups that underpin ecosystems such as invertebrates are poorly studied. Most research has been on larger animals, including the dangers that roadkill poses to road users.

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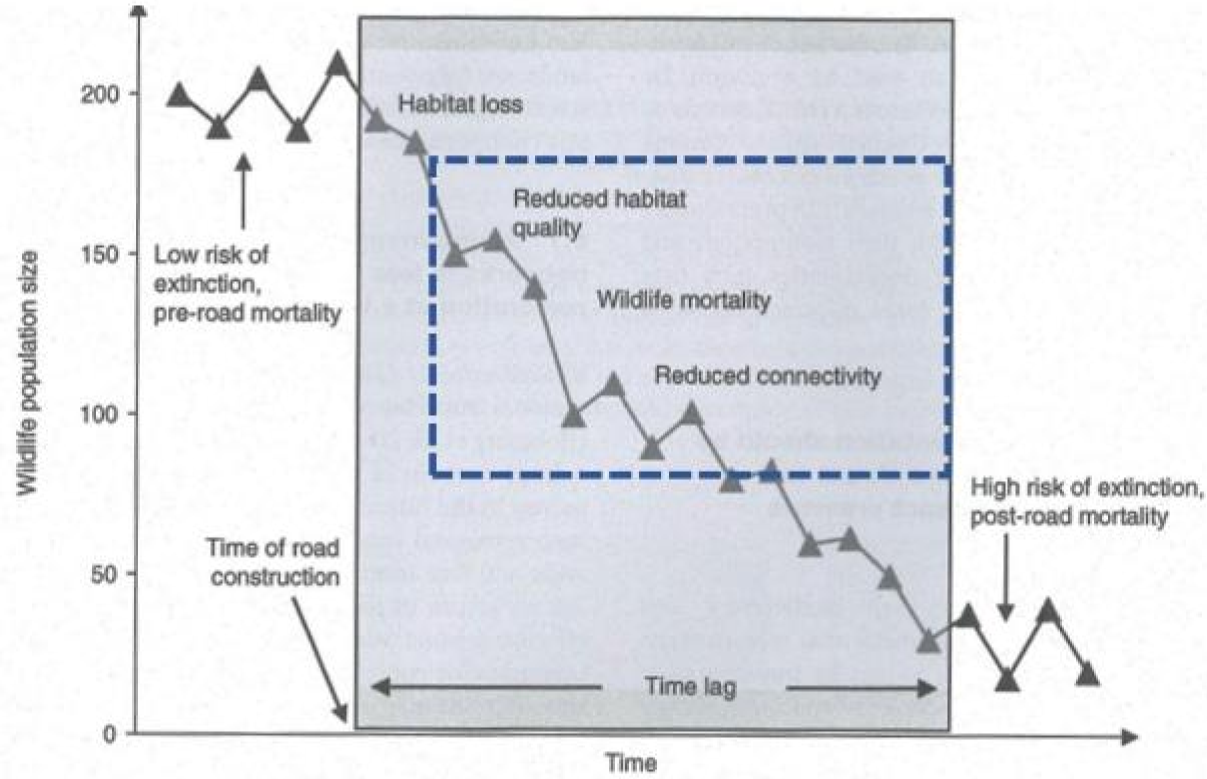
[6] Noting that many transmission lines include road access, although these roads are usually unpaved.

[7] Two early syntheses of road effects are a Swedish review by Andreas Seiler (2001), and an *Ecology and Society* special issue (April 2011) titled ‘Effects of roads and traffic on wildlife populations and landscape function’ (https://www.ecologyandsociety.org/issues/view.php?sf=41)

[8] Especially by the Australasian Network for Ecology & Transportation (ANET) (http://www.ecologyandtransport.com/).

Figure 1.4 Major ecological impacts of roads and traffic on animal populations and time lag (in the order of decades, shown in grey). The blue dotted line identifies effects due to road edges excluding the footprint at construction (adapted by van der Ree et al., 2015, from Forman et al., 2003).



In New Zealand, the Resource Management Act 1991 does not effectively consider cumulative effects from multiple roads across landscapes. In addition, the delayed nature of effects that occur after initial project completion (defects liability) and/or beyond consenting periods of 30–35 years also means such impacts of roads are probably underestimated (Figure 1.4).

1.2.4 Impacts of noise and vibration

Noise and vibration are key road edge-effects for a wide range of animals internationally, but very poorly understood in New Zealand where there has been little research on effects of traffic noise on native fauna. An exception has been research on long-tailed bats (Smith et al., 2017,[9] notably Appendix C). International research identifies road traffic as the most pervasive source of anthropogenic noise (Nega et al., 2013) and a major cause of long-distance impacts (120 to 1,200 m) (Forman et al., 2003; Reijnen & Foppen, 1995, 2006; Reijnen et al., 1996; Reijnen et al., 1997). This means traffic noise can degrade habitat near roads that is otherwise suitable, and areas with high road density are most affected (Cooke et al., 2020). Effects of noise are influenced by traffic volumes and types, road characteristics (ie, surface and geometry controlling vehicle acceleration/deceleration) and attenuation or exacerbation by adjacent topography and surfaces (AECOM, 2019[10]).

[9] https://www.nzta.govt.nz/assets/resources/research/reports/623/623-effects-of-land-transport-activities-on-NZs-endemic-bat-populations.pdf

[10] https://www.nzta.govt.nz/assets/Highways-Information-Portal/Technical-disciplines/Noise-and-vibration/Research-and-information/Other-research/national-land-transport-road-noise-map-2019-05-16.pdf

Traffic noise reduces the ability of animals to perceive natural sound. Hearing is an important way many animals locate prey or detect predators approaching, and how they communicate with their own species. Many birds use song to assess rivals and potential mates, and to define and defend territories (Barber et al., 2010). Noise-masking by traffic can obscure alarm calls that warn of approaching predators, and contact calls that maintain group cohesion (Francis & Barber, 2013). Noise-masking can therefore increase stress and disrupt communication. This can lead to changes in vigilance and foraging behaviour, decreased breeding success, lower breeding densities and/or higher mortality (Halfwerk et al., 2011; Shannon et al., 2016). Harding et al. (2019) reviewed causes and consequences of all anthropogenic noise on wildlife, concluding that responses of species were influenced by age/size, condition, sex, context, repeat exposure, prior experience, and presence of other stressors that exacerbate effects of noise stress. A meta-analysis by Kunc and Schmidt (2019) similarly found noise affects the majority of species and considered noise as a serious form of anthropogenic change and pollution as it affects both aquatic and terrestrial species. Meta-studies of birds have found rarer species and migratory species are more sensitive to noise (Cooke et al., 2020; Fahrig & Rytwinski, 2009; Reijnen & Foppen, 2006). Traffic can also cause ground vibrations, which can cause increases in stress hormones, or cause some animals to emerge from dormancy or initiate reproductive activity as a response to rainfall (potentially giant wētā; C Watts, pers. comm., 2020).

In the only southern hemisphere study of traffic noise impacts on bird song, Parris and Schneider (2009) looked at traffic noise impacts on grey shrike-thrush and grey fantail at 58 roadside sites in Australia. The grey shrike-thrush, which normally sings at a lower pitch than the grey fantail, sang at a higher pitch in the presence of traffic noise, but the grey fantail did not appear to change its song. The probability of detecting each species on a visit to a site declined substantially with increasing traffic noise and traffic volume; however, as traffic noise also makes it harder to detect birds by listening to birdsong, these changes may be due to impaired ability of surveyors to detect birds (Cooke et al., 2020).

International studies report reduced bat activity and abundance up to 1.6 km from roads, possibly due to noise interfering with echolocation (Berthinussen & Altringham, 2012). In a New Zealand study, Smith et al. (2017) report monitoring devices 200 m from highway edges are more likely to detect bats than devices near highways. The study also indicated that although activity of the edge-adapted, open-space foraging long-tailed bats could be high along roads, activity declined rapidly as traffic rates increased to 1,000 vehicles/night.

A review of international literature on responses of all animals to noise from 1999 to 2013 reported terrestrial wildlife responses begin at noise levels of ~40 dBA, and 20% of studies documented impacts below 50 dBA (Shannon et al., 2016). Barber et al. (2010) report daytime noise levels exceeding 41 dBA as far as 500 m from a road with 3,700 vehicles/day in Glacier National Park in the United States. Subsequent modelling identified noise loads on protected areas across the United States (Barber et al., 2011). The absence of data on effects of noise and vibration on native New Zealand species is a reason there are few, if any, transport projects where these effects are mitigated to enhance biodiversity outcomes. However, noise models are used to identify areas with effects on human health (AECOM, 2019). Modelled noise (as time-averaged decibels over 24 hours) indicates noise levels exceeding 55–59 dB on average at 25–50 m from the centreline for roads such as State Highway 73 (SH73, the Great Alpine Highway,[11] Canterbury) and at 200–300 m for roads such as State Highway 16 and State Highway 18 (SH16/18)[12] in Auckland. New Zealand highways include extensive mitigation of noise to reduce impacts on humans (see, for example, the SH16/18 case study in section 3).

[11] https://www.newzealand.com/nz/feature/the-great-alpine-highway/

[12] https://nzta.govt.nz/projects/sh16-18-connections/

1.2.5 Impacts of artificial light at night

Artificial light at night (ALAN) associated with roads is delivered as relatively constant *in-situ* road lighting (eg, streetlights) and highly variable lighting from individual vehicles (Forman et al., 2003). ALAN disrupts natural day–night and lunar cycles and can cause effects across diverse ecosystems (Gaston et al., 2014) because many animals and plants use these cycles as reliable environmental cues for flowering, breeding, orientation and navigation (Kempenaers et al., 2010).[13] At larger scales, and over longer periods, constant lighting ('sky-glow') can mask the lunar cycles (eg, McNaughton et al., 2021, 2022[14]). At small scales, ALAN from streetlights changes behaviour by attracting so many nocturnal insects that pollination by nocturnal insects may be disrupted. For example, Knop et al. (2017) reported a 62% reduction in nocturnal visits to plants resulting in a 13% decrease of fruit set despite the actions of daytime pollinators. Such impacts could be significant in New Zealand because many native plants are adapted for pollination by moths and other nocturnal insects (eg, many plants with white/cream flowers). By increasing the plant photoperiod, ALAN can also decrease seed germination and flowering, increase leaf senescence, and alter growth form (Bennie et al., 2016; Longcore & Rich, 2001).

ALAN attracts both insects and their predators. Anecdotally, street lighting attracts native nocturnal insectivores such as New Zealand bats[15] and ruru/morepork, increasing their foraging success, and shorebirds are reported to be roosting under lights (Longcore & Rich, 2001, 2004). Many aquatic insects are attracted to polarised light reflected off cars or roads and will choose these locations to lay their eggs, leading to hatching failure (Horváth et al., 2009). Artificial lighting is also reported as altering composition of aquatic and terrestrial insect communities, increasing predator and detritivore populations (Sullivan et al., 2019).

The death of threatened endemic seabirds has highlighted effects of inappropriate lighting in New Zealand. New Zealand is a 'seabird Mecca'. The 86 species breeding in our waters represent about a quarter of the global seabird fauna (370 species) and include most endemic and threatened seabird species (36 species; Lukies et al., 2019). New Zealand experiences of petrels and shearwaters being attracted to artificial lights is quite consistent with those elsewhere in the world (Rodriguez, Dann, et al., 2017; Rodriguez, Holmes, et al., 2017). The grounding of Hutton's shearwater (*Puffinus huttoni*) fledglings under street and other lights in Kaikōura township prevents these birds reaching the sea. Deppe et al. (2017) estimate that 0.1–0.3% of total fledglings ground under lights at Kaikōura, and many of these are rescued, with the population estimated to be growing at 3.5% per annum. Grounding affects 56 species of petrels and shearwaters worldwide (Rodriguez, Dann, et al., 2017; Rodriguez, Holmes, et al., 2017). Petrels and shearwaters also strike lit vessels at sea (Lukies et al., 2019). Night-feeding petrels may be attracted to lights because they feed on bioluminescent prey (Imber, 1975) or because they confuse lights with the moon, which they use for navigation (Lukies et al., 2019).

Westland petrels (*Procellaria westlandica*) flying to and from their mainland breeding colony sometimes collide with power lines, and adults and fledglings ground themselves under exposed lights, but the significance of these deaths is unknown (Waugh & Bartle, 2013). Key periods are mid-November and mid-January, when young birds depart their burrows for the first time (maiden flights). Effects of ALAN have not been studied on New Zealand land birds, reptiles or insects. However, nocturnal predated animals may avoid light in a similar response to that reported for treefrogs internationally, where rapid increases in light from headlights slow visual foraging and cause the frogs to remain stationary long after the light is removed

[13] A review and mitigation guidelines at https://www.awe.gov.au/environment/biodiversity/publications/national-light-pollution-guidelines-wildlife

[14] Ellery McNaughton completed her PhD on ALAN in areas of ecological importance using Auckland as a case study.

[15] Note that overseas research indicates some species of bats actively avoid lit areas (to avoid being preyed on).

(Buchanan, 1993). Rich and Longcore (2006) report open space above a road increases light in forested areas; the reflected light can become linearly polarised, which can affect animals that use such light for orientation and navigation. The location of streetlights is also important to consider in the context of predatory birds, some of which use lights as perches. Anecdotally, black-backed gulls use such perches along the Auckland motorways to enhance predation, which has included threatened species such as banded dotterels. Impacts of mitigation by shielding, dimming or turning off lights are readily observable by people and immediate, with no lag phase.

1.2.6 Impacts on roadside plants

Few New Zealand studies describe or quantify the impacts of road edges on humidity, light and moisture within forests. Instead, effects are inferred from studies of forest edges in pasture (Davies-Colley et al., 2000; Young & Mitchell, 1994) or logged forests (Norton, 2002). These suggest gross microclimatic effects and effects on vulnerable flora such as bryophytes penetrate 20–100 m, with ~40–50 m considered an ‘average’. The only impacts of roads supported with comprehensive New Zealand data are effects on plant species composition (Overton et al., 2002[16]; Smale et al., 2003; Sullivan et al., 2009[17]) and characterisation of road stormwater runoff (Moores et al., 2009[18,19]; Semadeni-Davies et al., 2010; Timperley et al., 2010). The studies on roadside plant species composition provide critical insights, given that (a) New Zealand has more naturalised non-native plant species than almost any other island worldwide, (b) these non-natives form about half of all ‘wild’ plants in New Zealand (Diez et al., 2009), and (c) our native plant communities appear particularly vulnerable to competition, given non-native plant species now dominate a wide range of lowland habitats (Hulme, 2020[20]).

The New Zealand roadside vegetation studies have four useful conclusions.

- First, roadsides through native areas are ‘weedier’ than adjacent landscapes, while those in intensively farmed landscapes are ‘more native’ and may act as native refugia and seed sources (Figure 1.5). This outcome is independent of road character – that is, it holds for single-carriageway roads in both native and farmed landscapes.
- Second, while some weeds can use roadsides as invasion corridors, many simply benefit from regular roadside disturbance (mowing and herbicide), which promotes and maintains their establishment. Some native species also benefit from roadside maintenance that controls competition for light, notably a variety of orchids. Common terrestrial orchids found on roadsides with suitable habitat and maintenance include *Pterostylis patens, Thelymitra longifolia* and *Microtis uniflora* (Lehnebach et al., 2005; Simcock et al., 2005) and rarer orchids like *Nematoceras iridescens* (Hansford, 2014[21]). Mowing height and timing needs to supress competing vegetation but allow seasonal ground-orchids to emerge and seed. For example, along SH12 in Waipoua Forest, roading contractors specifically manage tutukiwi (*Pterostylis banksia*, kauri green hood orchid; NZ Transport Agency, 2014b), which flowers from September to

[16] https://www.nzta.govt.nz/assets/resources/research/reports/221/221-A-methodology-for-assessing-the-biodiversity-of-road-networks-a-New-Zealand-case-study.pdf

[17] https://newzealandecology.org/nzje/2904.pdf

[18] https://niwa.co.nz/sites/niwa.co.nz/files/nzta_research_report_395.pdf

[19] The Catchment Contaminant Annual Load Model (C-CALM) was applied to Waterview Connection Project in Auckland (see https://www.nzta.govt.nz/assets/projects/completing-wrr/docs/docs-enquiry/evidence/evidence-18-jonathan-moores.pdf).

[20] https://link.springer.com/article/10.1007/s10530-020-02224-6

[21] https://www.nzgeo.com/stories/orchidelirium

November, by eliminating agrichemicals and mowing from marked zones where only hand-weeding is used.[22]

- Third, the low proportion of weeds on roadsides reflects that many weeds are likely still in the early stages of invasion in New Zealand.
- Fourth, the small proportion of weeds that do spread along roadsides include very aggressive, habitat-transforming species such as gorse, broom, Spanish heath, heather, pampas, tree lupin, honeysuckle (Figure 1.5) and cotoneaster (Overton et al., 2002; Smale et al., 2003; Sullivan et al., 2009).

Figure 1.5 A rural Manawatū road acts as a refuge for native tī kōuka/cabbage trees and a source of invasive honeysuckle vines. (Photo taken July 2021.)

1.2.7 Impacts and value of remnant roadside habitats

The disproportionate value of even small and/or degraded native remnants within depleted pastoral areas and urban areas has been quantified internationally (New et al., 2021) and in New Zealand studies, notably for invertebrates in Auckland (Watts & Larivière, 2004), Waikato (Harris & Burns, 2000) and Christchurch (Toft et al., 2019). These indicate roadside remnants in such contexts are likely to have beneficial ecological values if they persist. Clarkson et al. (2018) propose increasing native habitat to a minimum of 10% of the total land area in New Zealand. Protecting, maintaining, and enhancing ecological values (eg, through weed control) and buffering these areas to expand ‘core’ habitat and increase the overall size and shape to a level that increases the likelihood of persistence of native biodiversity should therefore be a priority. Areas with high potential for expansion of native vegetation or habitat are often located along riparian corridors or terrace scarps/cliffs where remnants are present beyond the road corridor and less impacted by adverse road edge-effects. Buffering is usually achieved by planting or activating regeneration of adjacent areas. Despite absence of data on effects of road-generated noise and light for most native species, measures to avoid or mitigate such effects should be considered where likely habits of vulnerable species are present.

[22] The epiphytic peka-a-waka orchid (*Earina mucronata*) is also specifically managed by identifying individuals to avoid during road envelope clearance. Fallen branches with epiphytic orchids (*Winika* orchids, *Drymoanthus adversus* and *Bulbophyllum tuberculatum*) are preferentially placed on roadsides where light conditions will remain relatively high rather than placed in adjacent forest.

1.2.8 Value of planted roadside habitats

Recent studies indicate conventionally planted forest and shrubland areas have relatively low biodiversity values for at least 20 years. After about this time, biophysical conditions start to favour regeneration of a wide range of shade-tolerant 'forest interior' native species (Wallace & Clarkson, 2019). In depauperate areas, successive management is also required to establish long-lived forest canopies with structural diversity, including epiphytes. In addition, permanent maintenance is also needed to prevent (re)establishment and dominance of non-native plant species in both planted areas and in remnants, at least in lowland areas with mild climates and abundant bird-dispersed weed sources (Sullivan et al., 2009; Wallace & Clarkson, 2019; see SH16/18 case study in section 3). Most New Zealand studies have not tested techniques to enhance soil, wood and litter invertebrates in rehabilitation. Such techniques would include direct transfer of plants and soil, and additions of coarse wood as habitat features (Cavanagh et al., 2018;[23] Griffiths et al., 2018[24]). These techniques offer the potential to broaden and expedite the biodiversity values of conventionally established areas.

1.2.9 Fragmentation

New Zealand studies on the effects of fragmentation on movement of plants, pest animals (eg, rats, possums, stoats) and native birds are increasing. Most support two national, multi-agency programmes: OSPRI NZ TB free (bovine tuberculosis) control and Predator Free 2050. Nearly all fragmentation studies have been conducted within an agricultural matrix; results may not be reliably transferred to forested (native or plantation) areas. Few studies include the barrier effects of roads, with their additional noise, light, vehicles and paved surfaces. Data on the width at which roads are barriers to movement of native animals are also based on sites in pastoral landscapes, with relatively very few native species. In New Zealand, most predators do not appear to preferentially use road surfaces – with the exception of cats and free-roaming dogs (Geyle et al., 2020; Robley et al., 2010) – although roadkill indicates many mammals use bridges (Brockie, 2007). Overall, most New Zealand rural highways are unlikely to be barriers to movement of most mammalian predators (ie, rats, possums, mustelids, hedgehogs and cats). Such animals dominate reported roadkill.

1.2.10 Roadkill

New Zealand is unusual in a global road ecology sense because most roadkill is invasive pest animals. Some researchers have therefore suggested roads could contribute to invasive species control by defining the edges of control zones, limiting re-invasion, or assisting with population monitoring (Sadleir & Linklater, 2016). Outcomes could be enhanced by targeting control measures at pinch-points where wildlife cross roads (Brockie, 2007; Glen et al., 2013).

Factors impacting roadkill are summarised by Seiler (2001) (Figure 1.6) and show how road, traffic and landscape factors interact. Figure A.7 in Appendix A also shows many of these factors with New Zealand fauna. Fahrig and Rytwinski (2009)[25] summarised how roadkill combines with other features to influence whether species respond positively or negatively to roads. Negative responses typically occur for animals with the following characteristics (potential New Zealand examples are provided in brackets, noting limited supporting data are available):

[23] This resource describes rehabilitation methods with case studies: 14 direct transfer and 19 use of coarse wood.

[24] This Australian paper describes use of chainsaw-carved, thermally stable cavities to mimic natural tree hollows for hollow-dependant fauna.

[25] http://www.ecologyandsociety.org/vol14/iss1/art21/

1. are attracted to roads but roadkilled (weka in farmed areas using road corridor habitat; cabbage white butterflies feeding on yellow flatweed flowers within mown roadsides; kāhu/harrier hawks scavenging roadkill)
2. have large movement ranges, low reproductive rates, and low natural densities (kiwi)
3. have a small body size, are not limited by road-affected predators at a population level and either (a) avoid habitat near roads due to disturbance (potentially birds that avoid noise and/or ALAN) or (b) show no avoidance and are killed (potentially small insectivore birds).

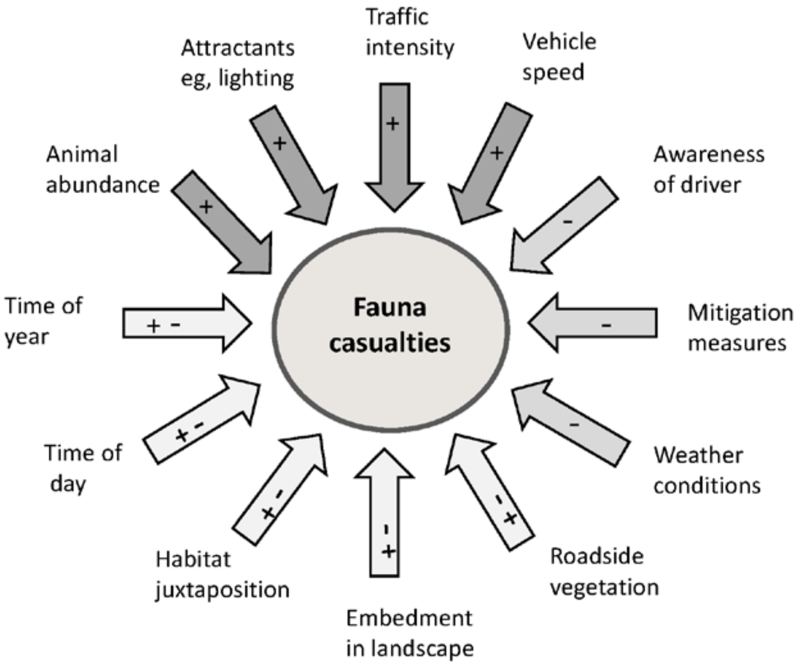
Animals that respond positively to roads were generally species that (a) are attracted to roads for an important resource such as food and able to avoid roadkill, and (b) do not avoid traffic disturbance but do avoid roads, and whose main predators show negative population-level responses to roads. Features that increase the vulnerability of individual small mammal species to roadkill were summarised by Andrews et al. (2015) and are presented below with New Zealand bird or invertebrate examples:

- how fast the animal moves (time on the road) – for example, slow-moving *Powelliphanta* snails[26] vs running weka, slow-flying kererū (wood pigeon) vs the fast, highly manoeuvrable tūī
- size and location of 'home range' relative to the road – for example, kiwi and North and South Island weka typically have home ranges large enough to cross roads[27]
- types and particularly frequency of movement: breeding and migration (seasonal), natal dispersal (annual), thermal regulation, or foraging – for example, some kororā/little blue penguins near Punakaiki cross the highway after foraging in the sea twice-daily to feed chicks in burrows
- learning and acclimatisation to roads – for example, young animals may be more vulnerable than older animals, such as scavenging hawks or seagulls
- risk-taking behaviour of individuals (varies within a species).

[26] Wirth et al. (1999) report just 1 of 169 Swedish land snails (*Arianta arbustorum*) successfully crossed an 8 m paved road with 500 vehicles/hr.

[27] Two studies provide information on home range sizes of weka: Bramley and Veltman (2000) for East Cape, and Freeman (2010) for Cape Foulwind near Westport. Both studies are in rural areas dominated by pasture.

Figure 1.6 Factors influencing the number of roadkill and type of impact (adapted from Seiler, 2001, p. 21).



Data on New Zealand native roadkill are extremely limited, with only a few published papers on endangered native bird species such as weka (Bramley & Veltman, 2000; Freeman, 2010) and kororā (Hocken, 2000). Freeman (2010) reported ~365 weka/year were killed by vehicles travelling over 25 km of rural roads around Cape Foulwind, which were trafficked by up to 2,000 vehicles/year. Most birds were male (73%), and the annual roadkill rate was 2–4% of the weka population, which was considered resilient to this pressure. In contrast, Bramley and Veltman (2000) reported roadkill accounted for 43% of tracked adult weka deaths in an East Cape area. In both cases, roadsides contained shrubland habitat that was cleared from adjacent farmland. Hocken (2000) reported roadkill rates of 10% (22 birds) in Otago and 54% (168 birds) where kororā crossed a West Coast highway, but impacts at a local population level were not reported. Grey literature indicates roadkill may reduce local populations of threatened birds such as kiwi, pāteke, kererū, and maybe kea. For example, Pierce et al. (2006) report an estimated 50 kiwi were killed on Kerikeri Peninsula roads between 1991 and 2005 (0.3 kiwi/month); however, local newspapers reported 6 kiwi killed in the area between January and August 2019, and 4 in the first 5 months of 2021 (0.75–0.8/month). Northland pāteke/brown teal and kiwi management plans specifically address roadkill. The plans identify roadside habitat that creates ecological traps within a farmed landscape, where the habitat is dense shrub cover (for kiwi) and drains (for pāteke) (Pierce et al., 2006); this also occurs for North Island and South Island weka in farmed landscapes (Bramley & Veltman, 2000; Freeman, 2010). Another causative factor for pāteke roadkill was blockages or waterfalls restricting their use of culverts to cross under roads that separate habitat.

Cousins (2010) studied 146 kererū with impact injuries collected from the lower North Island between 1996 and 2009. Cousins reported that 27% of the injuries were caused by vehicle collisions, and concluded kererū strike is likely to increase over time. This compares with 17% of 35 kererū with impact injuries collected in Auckland; 68% were killed by colliding with windows (Gill, 2006). Anecdotal evidence indicates some species-specific mitigation strategies are used in New Zealand to reduce roadkill – for example, exclusion fencing and/or underpasses for kororā in Punakaiki and removal of tree lucerne from motorway edges for kererū in Upper Hutt.[28] Signs have been installed in an effort to reduce roadkill of kiwi, weka, kea, kererū, pāteke, and kororā by raising driver awareness (Figure 1.7). Freeman (2010) reported signs were ineffective at reducing weka roadkill, potentially because local drivers caused most roadkill and became habituated to the signs. Overseas experience also indicates permanent signs typically have limited effectiveness at reducing roadkill. Reducing road speed limits to protect native species has not been implemented in New Zealand. Freeman (2010) reported that weka death rates increased with increasing speed, being four times higher at speeds over 60 km/hr, and identified reducing speed limits to below 60 km/hr during the vulnerable spring period as a mitigation option, along with road underpasses with barriers to prevent access to the roads and lead animals to tunnels.

Figure 1.7 Road sign installed near Kerikeri, Northland, in 2021 to reduce kiwi deaths. Although static signs are generally ineffective at reducing roadkill (van der Ree et al., 2015) they may serve other advocacy purposes.

1.2.11 Effects of road stormwater runoff

In contrast with roadkill, measures that reduce adverse effects of stormwater runoff from highways are well documented. Stormwater mitigation includes grey infrastructure such as catchpits, and road sweeping to reduce contaminant loads. Increasingly, mitigation uses features such as stormwater wetlands, ponds, unmown swales, and infiltration basins that have been planted with native species. These features serve to enhance water quality and reduce peak flow and volume of runoff. The contribution of these devices as native habitat, and the tolerance and potential impacts of elevated contaminants on fauna such as tuna/eels using these devices, have not been studied.

Road runoff can contain acute contaminants such as fire-fighting foams and spills of transported materials (eg, fertilisers, stock effluent) together with heat, which peaks in summer when road surfaces and receiving waters are generally warmest. Runoff also contains 'chronic' contaminants from vehicles: copper and zinc from brake pads and tyre wear; sediment from tyres and accumulated dust; hydrocarbons, nitrogen, sulphur,

[28] In the early 2000s, more than 100 kererū/year were estimated being killed along a 2.5 km stretch of SH2 planted with tree lucerne in the 1980s. Since removal of this prime food source in August 2018 no kererū deaths have been reported (see https://www.urbanwildlifetrust.org/portfolio/kereru-discovery/).

and lead as emissions from vehicle exhaust; and gross pollutants such as plastics. Runoff can also contain agrichemicals applied to roadsides and water tables to control plant growth. The delivery of these contaminants to surface waters and wetlands depends on road drainage, treatment, and efficiency of connectivity. Higher impacts are linked to runoff where ‘kerb and channel’ edges are connected directly with pipes that discharge to surface waters or wetlands. Lower-impact systems delay and treat runoff through the use of permeable pavements, vegetated swales, raingardens, treatment wetlands, infiltration basins and other methods of water sensitive design, which can be designed and maintained to enhance some habitats (Lewis et al., 2010[29]).

1.2.12 Effects on wetlands: a synthesis

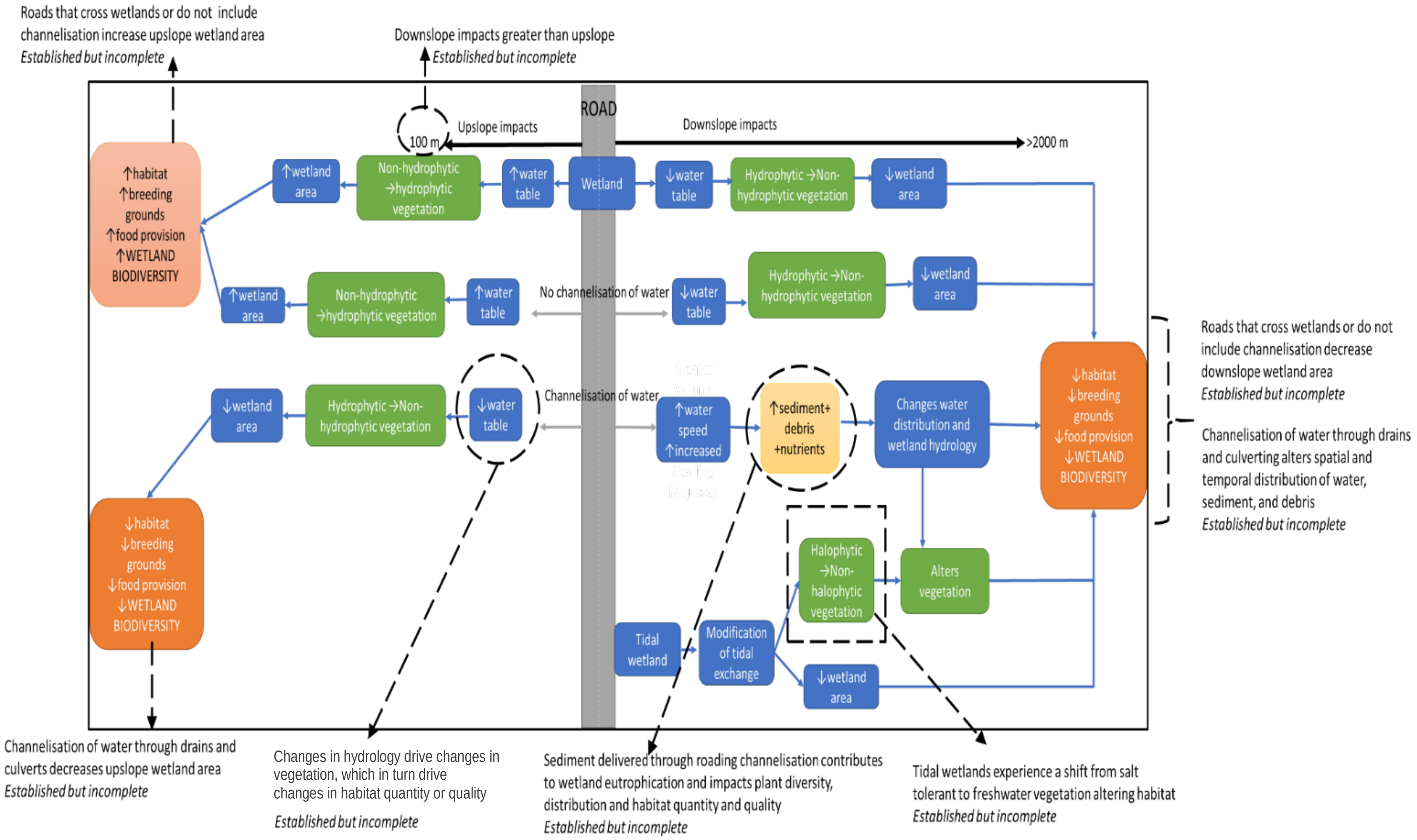
The literature review specifically assesses road edge-effects in the context of wetlands, given these features integrate terrestrial and aquatic systems, and their protection has been legislated under the National Policy Statement for Freshwater Management 2020 and the National Environmental Standards for Freshwater 2020. Wetlands are particularly vulnerable to effects of both road construction and ongoing operation. New Zealand wetlands are also vulnerable to a variety of impacts due to climate change (Bodmin et al., 2016). Results of overseas research on impacts of hydrological changes and road runoff are reflected in New Zealand studies. Both identify the major effects of roads on wetlands are driven by changes to hydrology, water-table depth and fluctuation, the speed at which road runoff enters wetland systems, and contaminants that accumulate over time. Over the long-term, some road-derived pollutants can accumulate to concentrations that have negative effects on biota, particularly trace elements such as copper, zinc and lead, and some agrichemicals. In the short term, road construction disturbance can elevate nutrients in runoff, with the adverse effects likely most severe on low-fertility, restiad-dominated communities.

New Zealand has very few amphibious species shown to be highly vulnerable to road runoff, as toads, salamanders and newts are not native to New Zealand. While New Zealand has three non-native *Litoria* frog species that may be found in roadside drains and wetlands, most remnant native frog populations are unlikely to be found near roads (exceptions are populations of Hochstetter’s frog in North Auckland’s Dome Valley and in the Brynderwyn Range, Northland). Further, New Zealand wetland fauna does not exhibit the seasonal migrations that result in large road mortality overseas for some newts, salamanders, tortoises, snakes, toads and frogs. Critical road effects with no New Zealand data are effects of light and noise on biodiversity of wetlands; however, international literature identifies wetlands as particularly vulnerable to light and noise as their low landscape position and short vegetation mean light and noise travels longer distances.

Figure 1.8 summarises effects of roads on wetland hydrology upstream and downstream and where roads either channelise water flows or avoid channelisation, and some flow-on effects on biodiversity.

[29] http://www.aucklandcity.govt.nz/council/documents/technicalpublications/tr2009083.pdf

Figure 1.8 **Edge effects of roads on wetland hydrology and flow-on effects on biodiversity. 'Established but incomplete' indicates research supports this statement but lacks detail. Effects of climate change are not specifically included.**



1.3 Analysis of New Zealand road environments

1.3.1 Method

The potential effects of roads in general, and New Zealand's highways in particular, were assessed by overlaying national datasets of road centreline data with land cover data from the Land Cover Database (LCDB) version 5.0 and land management information. The effects of roads on native biodiversity are likely to be greatest where adjacent land is in forests or shrubland (because species are adapted to humid, shaded conditions) or wetlands (due to impacts on hydrology) and where land is primarily managed for conservation. National databases were analysed to identify native-dominated land covers, New Zealand roads and state highways, and where effects of roads were considered likely to be most positive or negative. Databases included the Protected Areas Network – New Zealand (PAN-NZ[30]) database, useful because the impact of road edge-effects on biodiversity values is strongly influenced by the sensitivity of adjacent environments. The PAN-NZ database identifies areas primarily managed for conservation by the Crown, by territorial authorities, or by individuals through Queen Elizabeth II National Trust (QEII) conservation covenants. The LCDB v5.0,[31] launched in 2020, was used to identify wetlands and dominant vegetation at a 0.5 to 1 ha scale. The Threatened Environment Classification (TEC)[32] database (Walker et al., 2015) was used to identify where small, degraded remnants and regenerating ecosystems along roads are likely to have disproportionate ecological value because they are all that is left in that landscape. Road edge pressures were derived from data held by Land Information New Zealand (LINZ) and Waka Kotahi on vehicle numbers, noise contours and locations of streetlights, bridges and culverts. Maps were generated to show where roads intersect with particularly ecologically sensitive or depauperate areas.

1.3.2 Results

New Zealand's 16 local government regions tend to be either rich or poor in length of highway where the centreline is within 100 m of land managed by Department of Conservation (DOC) or QEII covenant holders (Figure 1.9, Figure 1.11, Table 1.1). The greatest length of such highways is in the West Coast (385 km), Waikato (214 km) and Bay of Plenty (122 km) regions. 'Conservation-poor' areas include Auckland, Gisborne, Taranaki and Hawke's Bay. In Gisborne, Auckland and Taranaki, over half of the 'conservation highways' are scenic reserves. However, in Hawke's Bay more than half of the sections of 'conservation highway' is stewardship land, which may have low conservation values. Over 1,300 km of New Zealand's state highways pass within 100 m of native forest and shrublands on public and private land. Such edges are likely to have biodiversity values at greater risk of degradation from road edge-effects linked to physical disturbance than lower-stature vegetation such as grasslands (without considering mitigation). For example, sparse New Zealand literature indicates gross microclimatic effects and effects on vulnerable forest flora such as bryophytes penetrate 20–100 m, with 40–50 m considered an 'average' for remnants in pasture.

About 163 km of New Zealand's state highways pass within 50 m of wetlands, with highways through flax land in the West Coast (5 km of state highway) and Manawatū-Whanganui (9 km of state highway) regions. Wetland and flax lands may include engineered wetlands for stormwater treatment or wetlands induced by linear infrastructure, but neither are able to be differentiated using available databases. The Waikato region

[30] https://data.linz.govt.nz/layer/53564-protected-areas/

[31] https://lris.scinfo.org.nz/layer/104400-lcdb-v50-land-cover-database-version-50-mainland-new-zealand/ and https://www.landcareresearch.co.nz/publications/innovation-stories/innovation-articles/land-cover-database-v5-launched-in-2020/

[32] https://www.landcareresearch.co.nz/tools-and-resources/mapping/threatened-environment-classification/

has the most ‘wetland’ highway edge, while Manawatū-Whanganui, Bay of Plenty, West Coast and Northland each have 17–18 km of state highway edges categorised as ‘wetland’ in the LCDB v5.0.

In large areas of intensively farmed parts of Waikato, Canterbury, Manawatū-Whanganui and Hawke’s Bay, most roadsides pass through areas dominated by grassland and cropland (with low biodiversity values) (Figure 1.12). Establishing specific native habitats along these rural roadsides where native species abundance is limited by lack of habitat can also provide co-benefits to owners of adjacent land through stock shelter and shade. Overseas studies show roadside margins also enhance pollination and predation of invertebrate pests in adjacent fields. However, the greatest co-benefits from establishing native wetland, shrubland and forest habitats along roadsides may be realised in suburban and urban areas where health and wellbeing benefits to people may be realised both directly and through mitigating air quality and noise effects of roads. Waikato (163 km of state highway), Canterbury (179 km of state highway), Auckland (128 km of state highway), Bay of Plenty (106 km of state highway) and Otago (108 km of state highway) each have over 100 km of state highway edges passing through urban areas. Auckland has by far the highest highway density (0.11 km/km^2) (Figure 1.10), but Waikato (1,848 km), Canterbury (1,523 km) and Otago (1,163 km) have the greatest highways length. No other regions exceed 1,000 km of state highway.

Auckland highways have the highest AADT volumes, exceeding 50,000 AADT, but the vast majority of New Zealand state highways receive less than 5,000 vehicles/day (Figure 1.10). This low volume by international standards reduces effects of noise, stormwater contaminants and air emissions, which are strongly correlated with traffic volumes. Applying a conservative 100 m buffer from all road centrelines shows 32% of the Auckland region and 5–11% of all other regions (excepting West Coast) could be impacted by some road edge-effects.

Coasts, wetlands and lakes are highly vulnerable to ‘barrier’ effects of roads for species that move from water to land (eg, to feed, roost or breed). They are also highly vulnerable to adverse effects of artificial light because water can reflect light and amplify its spread (in contrast to forested areas). Overlaying maps of highway streetlights, conservation land or coastlines within 100 m of the highway centreline, and wetlands or lakes within 50 m of the centreline, identified potential hot spots at a national scale (Figure 1.13). Areas near substantial ‘non-highway’ lighting were removed, such as the coastal cities Auckland, Tauranga, Gisborne, Napier, Wellington and Nelson. The remaining highway hot spots included the base of the Karikari Peninsula, the Hokianga and Kāwhia harbours, the Coromandel Peninsula, National Park (wetland), Motueka, Punakaiki and Granity (West Coast), and Tiwai Point (Invercargill). Roading investment that mitigates effects of streetlights and barriers on vulnerable species or ecosystems in these areas has delivered biodiversity benefits at Punakaiki.

Figure 1.9 Length of road adjacent to conservation land, by region. The road length is counted as adjacent if it is within 100 m of a highway centreline, and in some cases counts both sides of a state highway. Note: this does not include Auckland regional parks. Waikato excludes 4.4 km in Huntly Bypass, and Wellington excludes 11.1 km of Transmission Gully passing through regional parks and DOC-managed land.

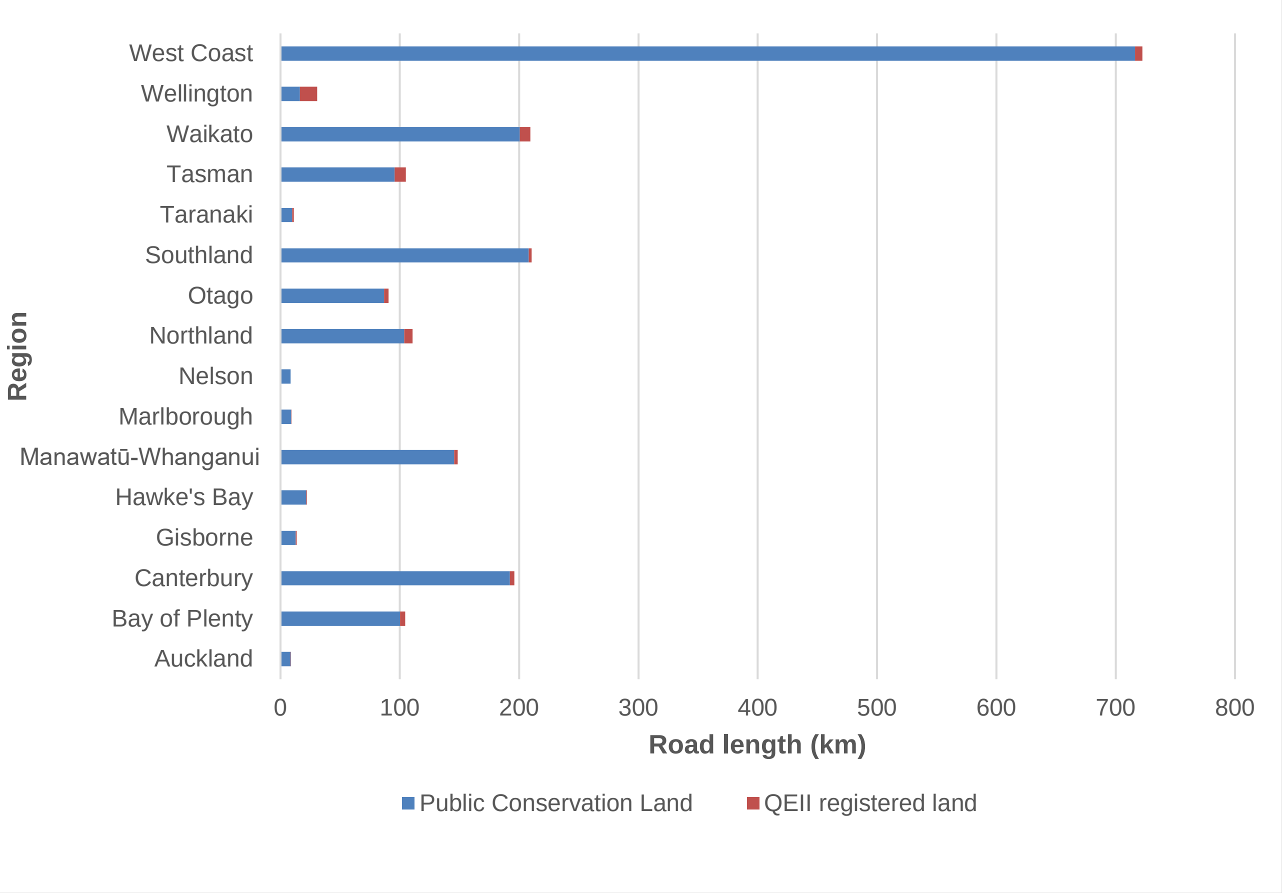


Table 1.1 Key road characteristics in each region: length of state highway (SH) and all roads; road density; percentage of area in each region within a 100 m zone of influence (ZOI) from any road; and length of state highways that have specific land cover classes within 50 m of the centreline of the highway for wetlands and 100 m for indigenous forest and pasture. Indigenous forest was the sum of LCDB v5.0 classes: Broadleaved Indigenous Hardwoods; Indigenous Forest; Mānuka and/or Kānuka; Matagouri or Grey Scrub. Fernland is excluded.

Region	SH length (km)	Total roads length (km)	Total road density (km/km^2)	Road ZOI as % of region (100 m)	SH length near wetlands (km)	SH length near indigenous forest (km)	SH length near pasture (km)
Auckland	523	8,028	1.63	32	4.7	15	158
Bay of Plenty	772	4,364	0.36	7	18.0	122	416
Canterbury	1,523	16,641	0.37	7	8.0	63	1,020
Gisborne	331	2,246	0.27	5	4.2	39	202
Hawke's Bay	532	4,720	0.33	7	10.0	60	321
Manawatū-Whanganui	982	9,012	0.41	8	18.3	85	724
Nelson/Marlborough	658	4,224	0.21	4	4.8	167	344
Northland	837	6,734	0.54	11	17.7	91	629
Otago	1,163	10,300	0.32	6	4.9	36	862
Southland		7,358	0.23	5	10.8	84	611
Taranaki	806	3,896	0.54	11	2.1	10	320
Waikato	1,848	11,910	0.48	10	35.6	214	1,238
Wellington	362	4,458	0.55	11	6.0	31	99
West Coast	874	2,740	0.12	2	18.6	385	357
TOTAL	**11,616**	**96,631**	0.36	n/a	**163.6**	**1,334**	**7,311**

Figure 1.10 Map showing state highways coloured to show traffic volume (as AADT in vehicles/day). AADT varies from < 5,000 vehicles/day to over 50,000 vehicles/day.

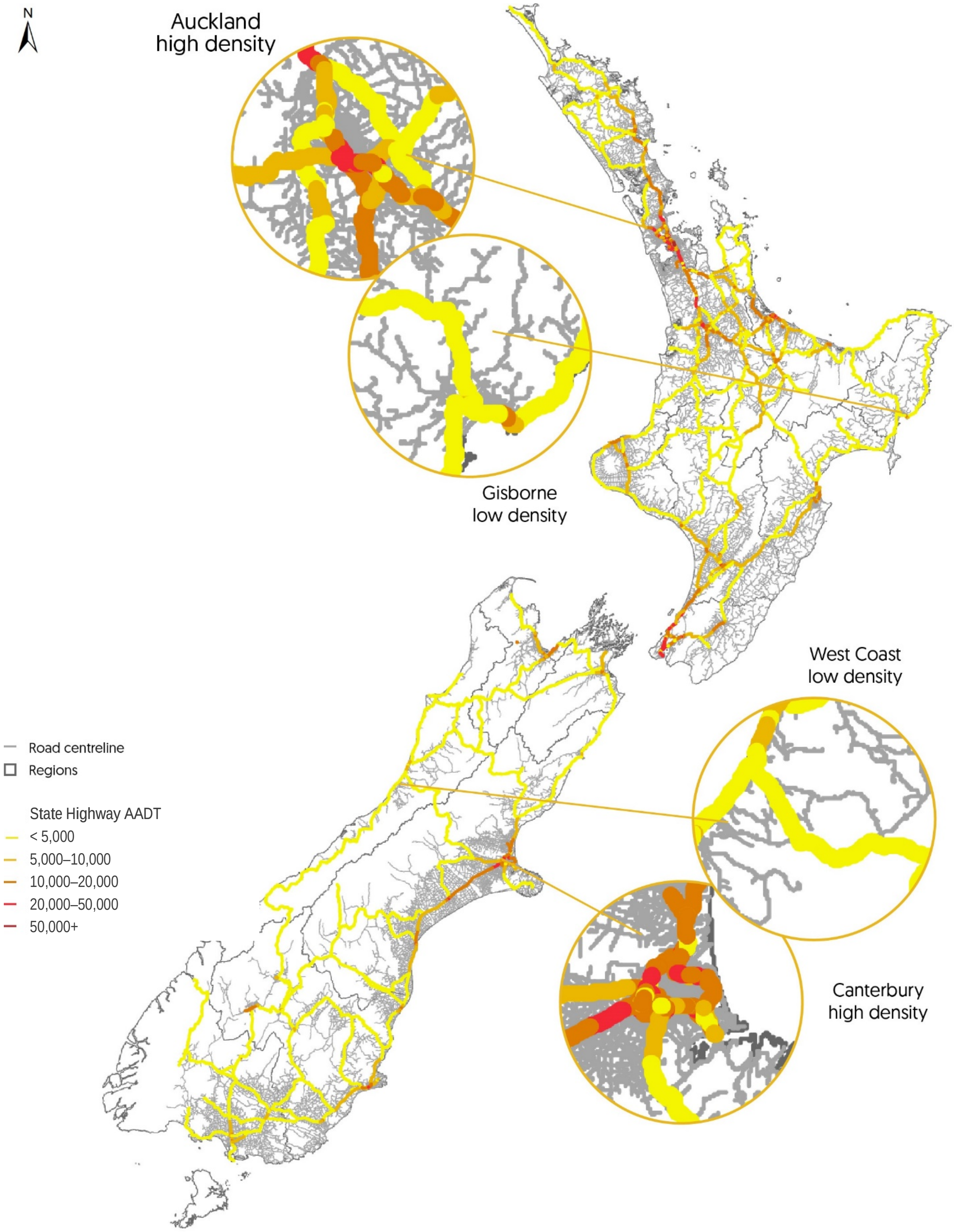


Figure 1.11 Map showing state highways and land in forests or managed for conservation by DOC or QEII covenant holders (2020 data). Insets contrast Gisborne, which has very little highway within 100 m of land managed for conservation, with the West Coast, which has the greatest length of highway near such land.

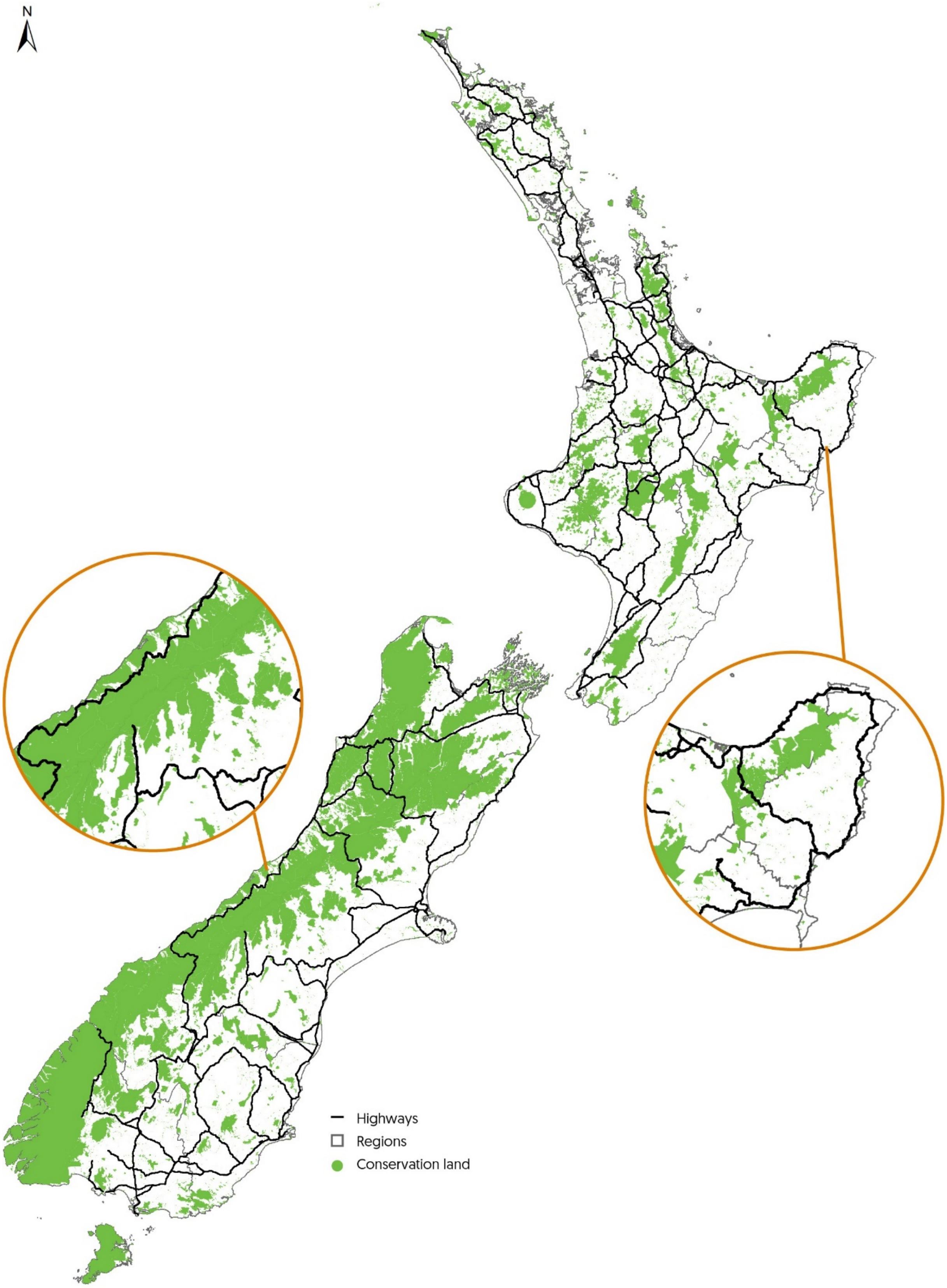


Figure 1.12 Map showing how state highways are concentrated in areas with the most threatened ecosystems (< 10% indigenous cover left). The five circles show the percentage of cover adjacent to the state highways that is in pasture/cropland (light green), native forest (dark green) and urban (grey) cover.

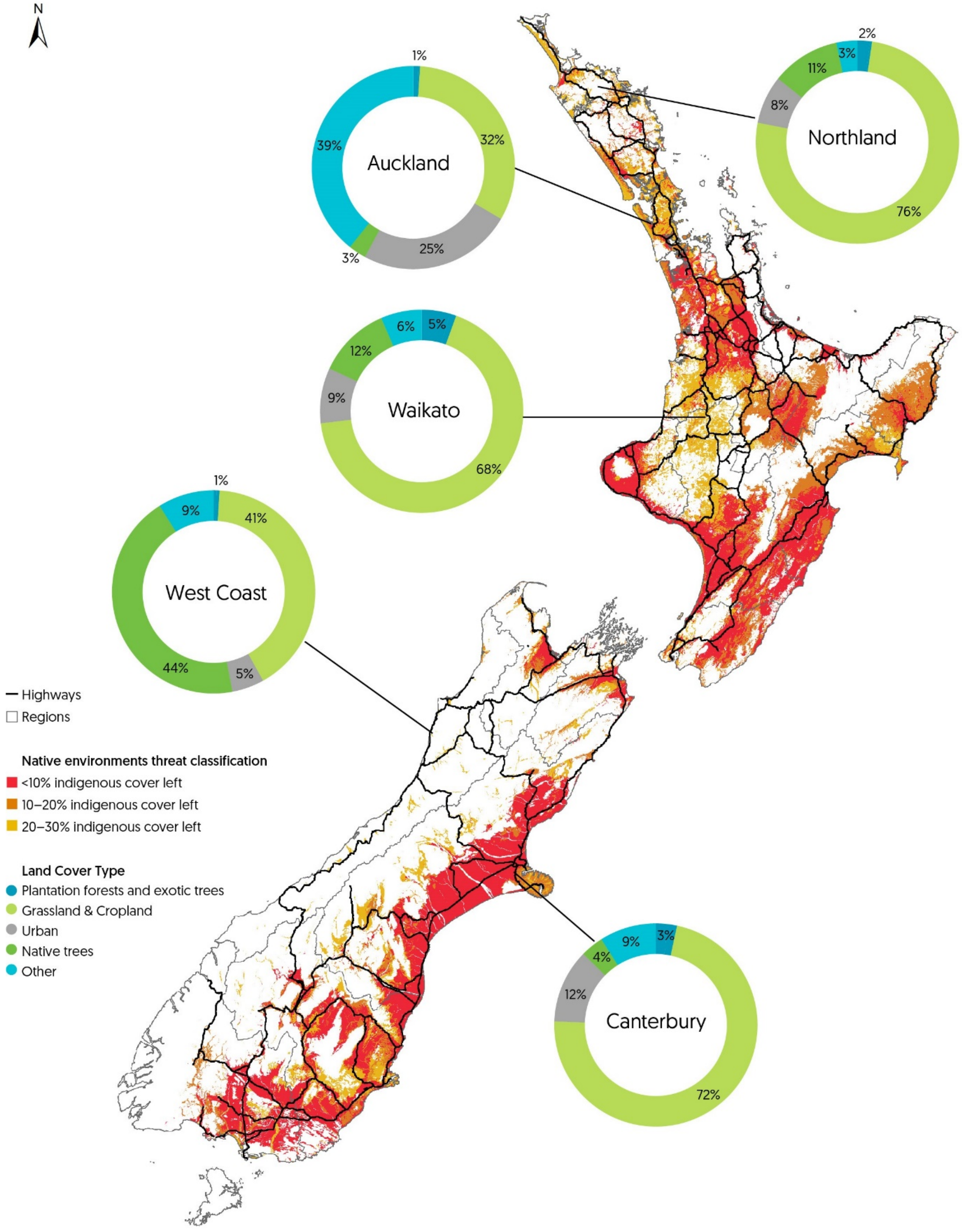
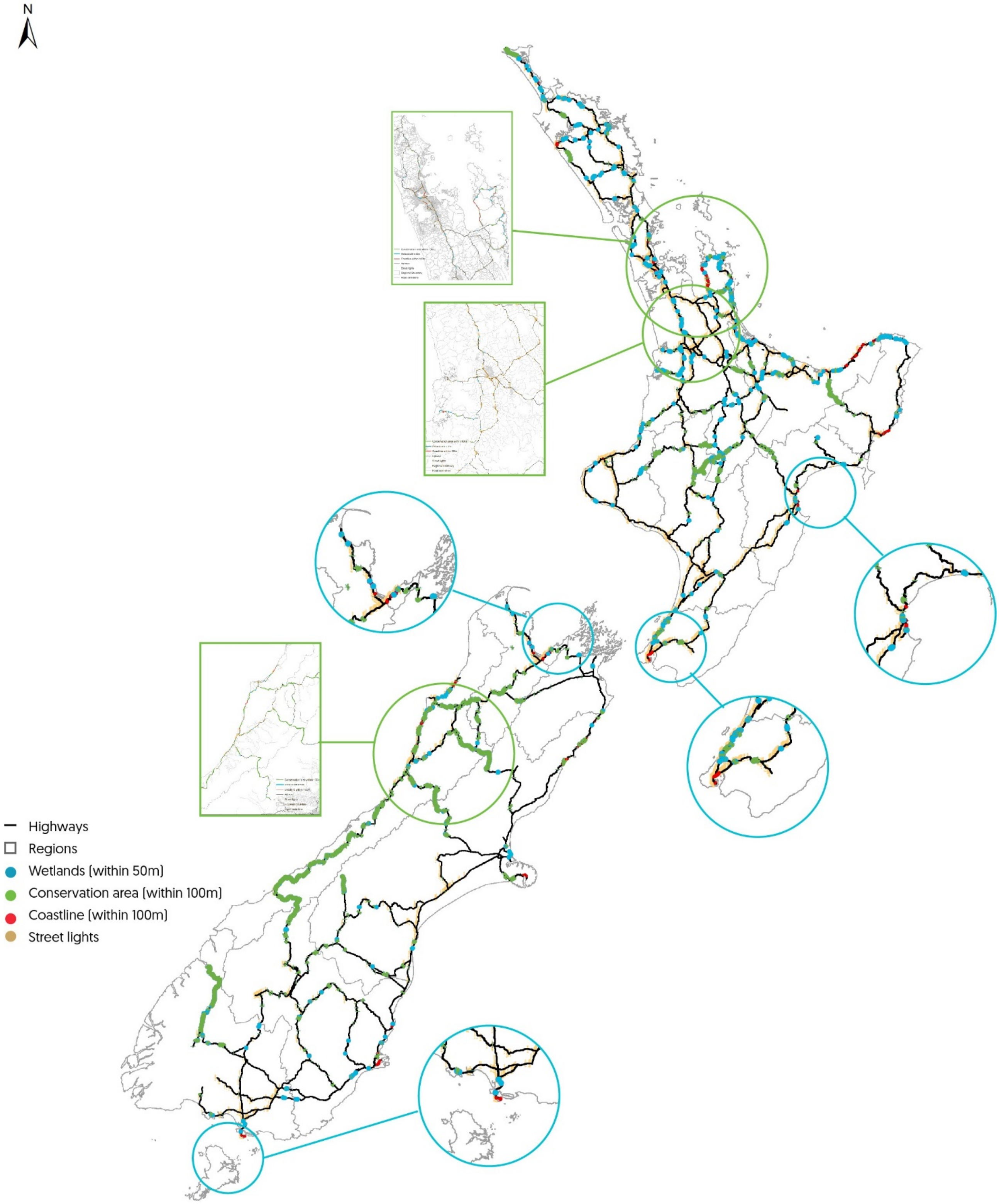


Figure 1.13 Map showing where state highways intersect with coasts, wetlands and native vegetation and lengths of highway with streetlights. These are 'hot spots' of potential negative effects.



2 Road edge-effects assessment

This section proposes a method to assess road edge-effects on biodiversity at a project scale. By identifying edge-effects, the method aims to avoid or mitigate negative effects on biodiversity and enhance positive effects. The method uses methods of identifying areas, species and ecosystems from databases and the literature review to develop summary tables of edge-effects grouped into the seven categories of road edge-effects.

The draft method was presented to the project steering group in April 2021. It was then applied in two contrasting case studies:

1. modern, high-volume highways in Auckland (SH16/18, section 3)
2. sections of old, low-volume highways in Canterbury's Waimakariri Basin (SH73, section 4).

Examples from these two case studies are used throughout the section to illustrate the assessment method.

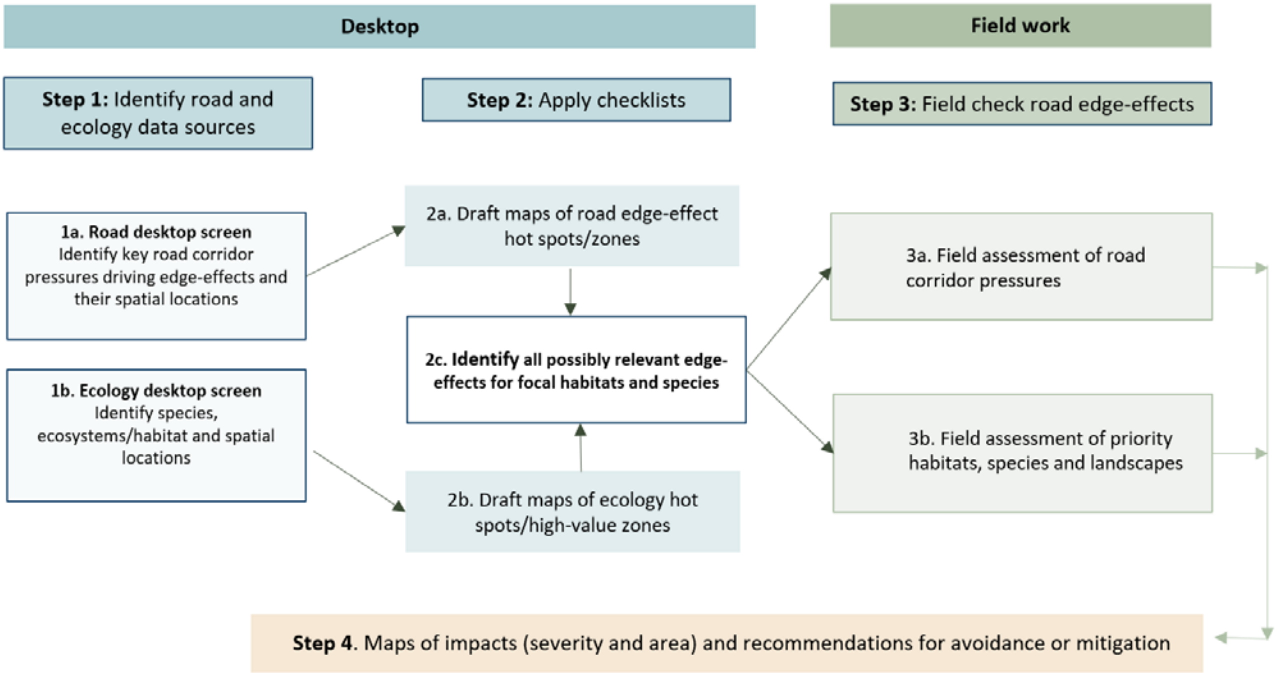
2.1 Introduction

The road edge-effects[33] assessment is a four-step process (Figure 2.1). The first two steps are desktop analyses that help make assessment of edge effects more efficient by focusing time spent in the field on areas with high impact and/or high ecological value, and features not identified by desktop studies. The third step is a rapid field verification that delivers information used in Step 4. Step 4 produces final maps that identify locations of priority edge effects and pressures. It also identifies options and areas for avoidance or mitigation – that is, adopting the effects management hierarchy. These options are also informed by using a spreadsheet that summarises road edge-effects and factors that generally exacerbate or mitigate specific road edge-effects.

In capital projects this process would be followed by detailed field studies to confirm ecological values, and engineering optimisation. This road edge-effects assessment process does not assess direct loss of habitat due to the road footprint. However, it includes habitat degradation and roadkill as important edge effects. The project scope requires a focus on terrestrial effects; however, many common aquatic impacts can be inferred from the steps that assess stormwater runoff and where roads cross watercourses and wetlands.

[33] Edge effects are defined and described in section 1.2 (Literature review) and summarised in section 5. The use of checklists is also designed to help users of the road edge-effects assessment method consider a wide range of potential edge effects related to biodiversity.

Figure 2.1 Proposed steps in road edge-effects assessment for land transport infrastructure.



2.1.1 Step 1: Identify road and ecology data sources

Step 1 identifies road and ecology data underpinning the draft edge-effect zone (Figure 2.1).

2.1.1.1 Step 1a: Road desktop screen: Identify key road corridor pressures driving edge effects and their spatial locations

Draft edge-effect zones (aka ‘zones of influence’) are initially defined by lines drawn 100 m and 500 m from the road centreline[34] on base maps with the LCDB and aerial photographs (Figure 2.2). During the field survey, potential effects within narrower zones (ie, 50 m either side of the centreline, the ‘construction zones’ and ‘clear zones’ (see section 1.2.2) will be a particular focus, but the 100 m and 500 m zones ensure that more distant native remnant habitats and effects that have larger potential spread (eg, light and noise) are considered.

Data on road factors (Table 2.1) are overlaid on a base map to help identify key pressures; the base map could be an aerial photograph or the LCDB (eg, the LCDB v5.0 is used in Figure 2.2). The road factors that indicate corridor pressures on biodiversity were extracted from public Waka Kotahi databases and a ‘private’ Road Assessment and Maintenance Management (RAMM) database. Table 2.2 identifies an indicative subset of layers relevant to habitat quality. Other layers may be useful for specific sections and for smaller sites (eg, digital elevation models, soil maps, wind speed/direction) depending on the features that identify the road edge-effects. In future, new and expanded data are likely to be available. For example, the RAMM database may be updated to include assets that protect ecological values such as stormwater treatment wetlands and ponds (noting these assets may also have their own ecological values), wildlife exclusion fences and wildlife conduits (particularly fish passages).

[34] Originally this was the road corridor, but for consistency, the CoreLogic centreline (provided by Waka Kotahi) was used as a basis – this is provided for each lane in a multi-lane highway. If the road edge is available, a shorter distance (eg, 50 m) could be useful.

Figure 2.2 SH16/18 case study area with 100 m and 500 m buffers from road centreline drawn on the LCDB v5.0 map.

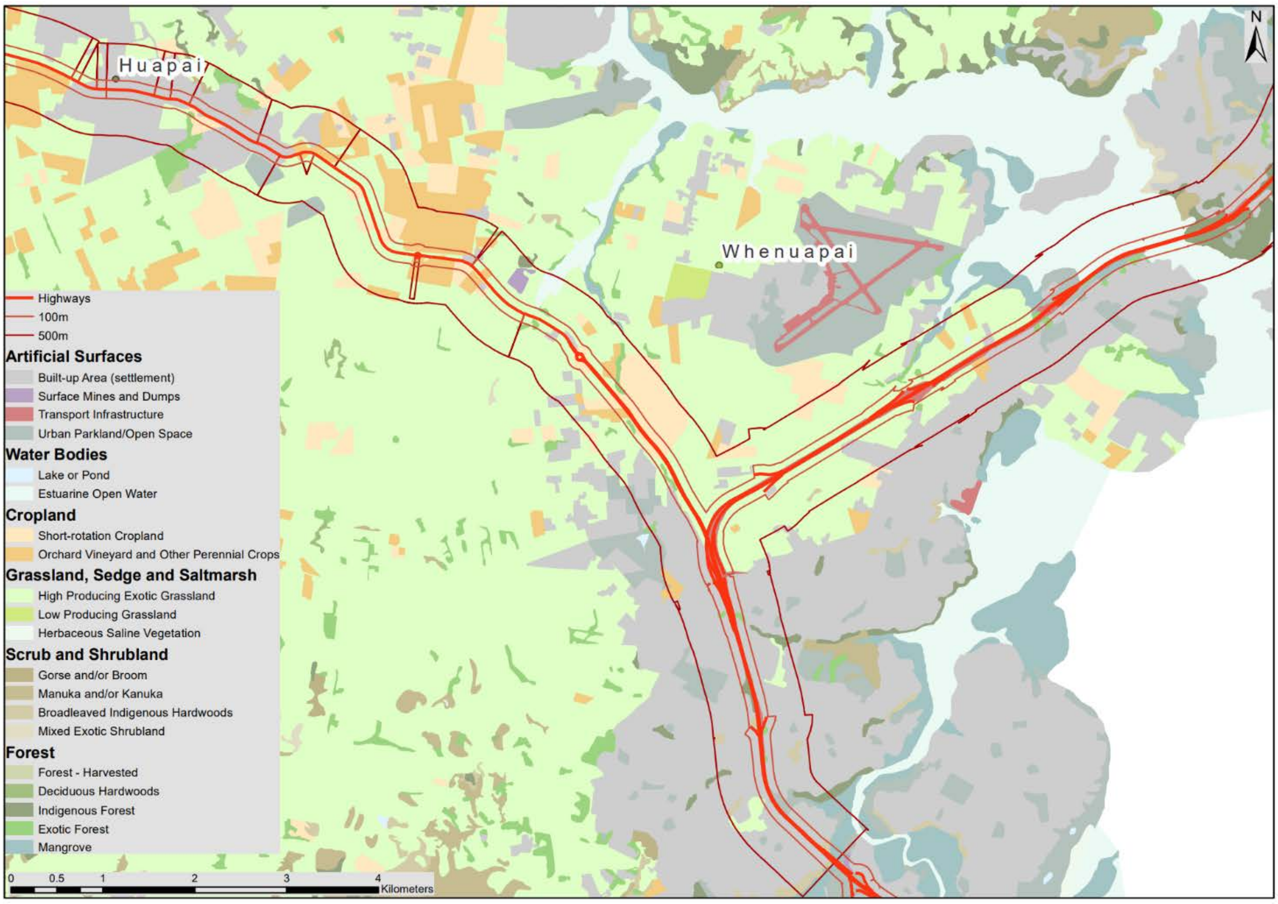


Table 2.1 Geographic information system (GIS) layers used to form a draft road edge-effects 'pressure' and 'hot spots' map for field verification.

Map/Layer	Description and rationale
Waka Kotahi road data	• Road centreline* (RAMM_CL#) • Bridges* (detail in Bridge data system) – however, most bridges are easily identified in a ground assessment as they are individually sign-posted • Culverts[35] from 'Drainage database', selecting attribute 'drain type' to only show 'culverts'# • Street lighting – point data on streetlight assets# • Noise wall# – metadata includes wall construction material, height and offset[36]
Traffic counts	AADT* and % heavy vehicle* (seasonal traffic data, and day/night data could be useful refinement for ecological impact assessment)
Waka Kotahi effects data	Noise contours – dB levels in $L_{Aeq(24)}$# [37]
Waka Kotahi effects data	Nitrogen oxides (NO_x) and sulphur oxides (SO_x) emissions map* [38]
Waka Kotahi property	Property owned by Waka Kotahi#

* indicates data are publicly available through LINZ or Waka Kotahi public websites
# indicates data layers provided by Waka Kotahi for this project

Noise

Noise is a key road edge-effect, as noise can spread a long way from roads (120 to 1,200 m) and degrade habitat that is otherwise suitable (Forman et al., 2003; Reijnen & Foppen, 1995; Reijnen et al., 1996; Reijnen et al., 1997). Waka Kotahi-modelled noise provides a variable-width buffer designed to protect human health and wellbeing. The lowest modelled noise contour provides traffic noise of 55–59 dB (average over a day, Figure 2.3). Noise contours reflect vehicle numbers (AADT with % heavy vehicles), topography, and presence of noise walls/bunds. In the two case studies described here, the average distance from the centreline to the edge of the limit was 25–50 m (SH73) and 200–300 m for SH16/18 (Figure 2.3). Waka Kotahi guidance 'strongly discourages' noise-sensitive activities within 20 m of a road edge, and there are no development restrictions beyond 80 m from the road edge (Figure 2.4).

In the absence of any New Zealand research defining thresholds at which road noise adversely affects native bird or invertebrate species, the 55–59 dB contour is used as a boundary representing a level at which noise effects are likely to be negative. The 55–59 dB level is designed for humans, and most research is based on human hearing (eg, thresholds and sensitivities relative to background noise). Other species have different frequency and hearing sensitivities and rely on hearing in different ways (eg, to hear predators or enforce boundaries of home ranges). A review of literature on responses of all animals to noise from 1999 to 2013 reported terrestrial wildlife responses begin at noise levels of ~40 dBA, and 20% of studies documented impacts below 50 dBA (Shannon et al., 2016). These thresholds do not consider background noise, which can either mask (SH16/18 case study) or emphasise road-generated noise (SH73 case study). The noise contours are measured as an average over 24 hours; they are likely to peak during the daylight hours and be

[35] 'Drain Type' includes 30 different attributes, of which 'culverts' are the most numerous (45,691). Stormwater treatment devices that may provide habitat values (wetlands and stormwater ponds) are not captured in the RAMM database. Fish passage is recorded at only five sites, so at present this is not useful.

[36] Vehicle safety barriers made from concrete could be useful to include where they act as barriers to wildlife, but these are best to assess in the field so are not included.

[37] $L_{Aeq(24h)}$ is time-averaged A-weighted sound pressure level over 24 hours, measured in dB (decibels, the unit of sound).

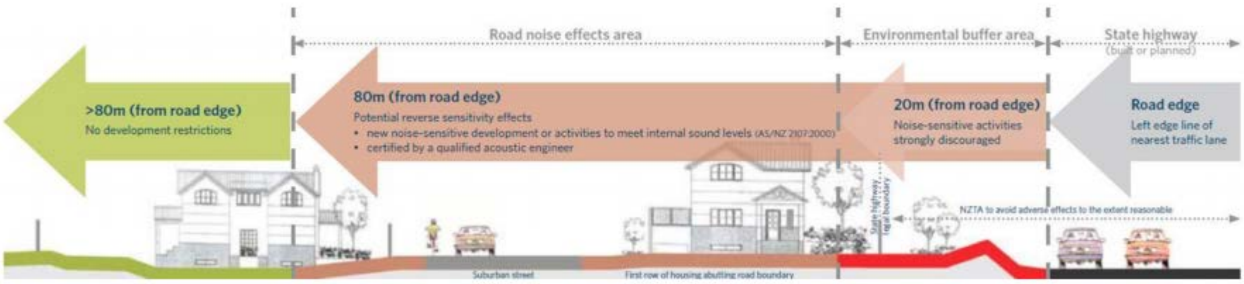
[38] https://www.nzta.govt.nz/roads-and-rail/highways-information-portal/tools/air-quality-map/

lower at night. This average noise may not align with periods that influence animals. The impacts of noise are likely to be greater when animals are active (eg, at night for nocturnal species, or in the evening and morning for crepuscular species) and during critical times of the year (eg, prior to breeding when establishing territories, or when migratory species are present).

The locations of noise walls are recorded in the RAMM database, and these are useful to cross-reference with noise contour maps – that is, noise contours are narrower where noise walls are present and generally wider over bridges (Figure 2.3). However, the RAMM database does not include noise barriers created using earth bunds or mounds (because these are not structures that require maintenance), so bunds need to be identified in field surveys. RAMM data enable an assessment of the likely effectiveness of noise (and safety) barriers at reducing movement of animals as barrier height and materials are specified.

Figure 2.3 Noise walls and modelled noise contours along highways and larger feeder roads for SH16/18. The lowest noise level marked (in blue) is 55–59 dB $L_{Aeq(24)}$. Arrows indicate where noise walls narrow the width of the 55–59 dB contour.

Figure 2.4 Diagram showing different highway noise areas for people.



Lighting

The impacts of light are also linked to AADT, but more specifically to the number of vehicles at night, and the spread, intensity/wavelength and flicker of streetlights. Most streetlights are mapped in the Waka Kotahi RAMM database (Figure 2.5). However, the SH16/18 case study indicates some Waka Kotahi lighting assets may be inconsistently mapped, so within a target road section it is useful to review observations and streetlight metadata to identify what lights are, and are not, included (and then spot-check in the field). The characteristics of the light created (eg, the wave lengths/spectrum and flicker) are not defined in the RAMM database, and this limits the ability to map its 'spread' of influence in a way comparable to noise.

Knowing the location of current and proposed streetlights is particularly important where vulnerable native animals are present and may be affected. There is no information on the effect of ALAN on native New Zealand land birds; however, increasing data are available for New Zealand petrels and shearwaters being attracted to artificial lights, which are consistent with data elsewhere in the world (Rodriguez, Dann, et al., 2017; Rodriguez, Holmes, et al., 2017). New information will become available as Waka Kotahi-led investigations on characterisation of street lighting, and effectiveness of turning off streetlights at Punakaiki in November and December 2020 on Westland petrel 'grounding',[39] are completed. New Zealand is a 'seabird Mecca', with 86 species breeding in our waters (Lukies et al., 2019), so the potential costs of inappropriate lighting on particular seabirds may be high. The *National Light Pollution Guidelines for Wildlife* (Commonwealth of Australia, 2020)[40] is a comprehensive summary that includes specific appendices covering seabirds, migratory shorebirds, and bats.

Vulnerable New Zealand species may have very large home ranges (eg, bats) and be particularly vulnerable only at certain times of the year (eg, the land-nesting seabirds, petrels and shearwaters during their maiden flight from breeding ground to the sea; Deppe et al., 2017). However, such maps are not available at a regional or national scale. In New Zealand, ALAN effects have not been reported for land birds, although street lighting has been reported to attract native nocturnal insectivores such as New Zealand bats[41] (Smith et al., 2017)[42] and, anecdotally, also ruru/morepork. Many insects are attracted to lights, and lighting has been reported as disrupting nocturnal pollination and therefore contributing to a decrease in plant reproduction (Knop et al., 2017). However, such lighting may also allow extended feeding of some wetland and shorebird species (Longcore & Rich, 2001). Internationally, ALAN may have important evolutionary consequences by encouraging earlier breeding (due to changing length of day or night; Kempenaers et al., 2010).

Finally, the location of streetlights is also important to consider in the context of predatory birds, some of which use lights as perches. Anecdotally, black-backed gulls use such perches along the Auckland motorways to enhance predation, which has included threatened species such as banded dotterels.

[39] 'Grounding' is landing of seabirds in places where they are unable to take off as these birds need elevation to be able to fly. Grounded birds are vulnerable to predators and car-strike if they land near roads.

[40] https://www.awe.gov.au/sites/default/files/documents/national-light-pollution-guidelines-wildlife.pdf

[41] Note, however, that overseas research indicates some species of bats actively avoid lit areas (to avoid being preyed on).

[42] https://www.nzta.govt.nz/assets/resources/research/reports/623/623-effects-of-land-transport-activities-on-NZs-endemic-bat-populations.pdf (Appendix 2 has a graph of road vehicles vs bat activity.)

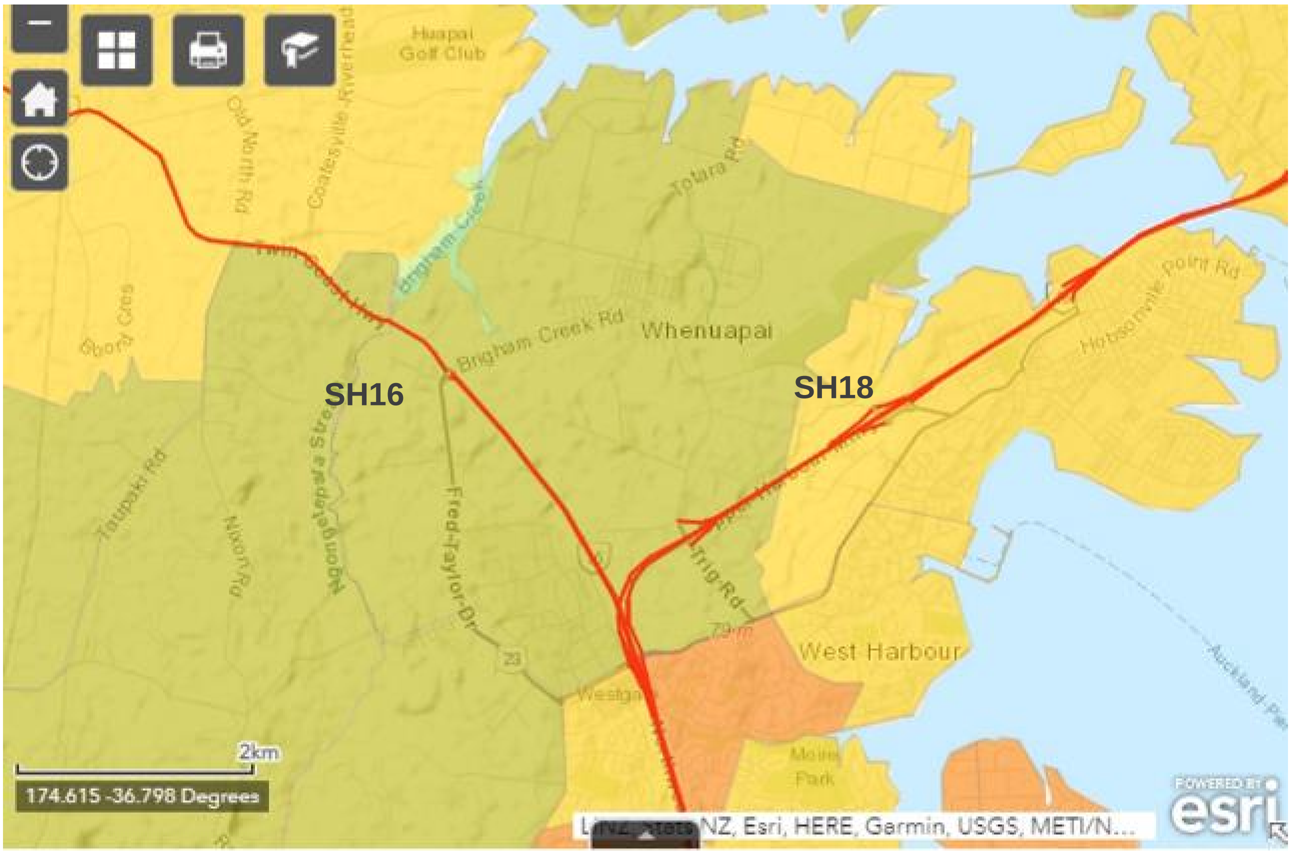
Figure 2.5 Location of streetlights (yellow dots) and Waka Kotahi-administered Crown land (pink) along SH16 (left-hand road) and SH18 (right-hand road).

Air quality

Modelled air quality across New Zealand is able to be accessed on the Waka Kotahi website.[43] Figure 2.6 shows modelled 24-hour average amounts of PM_{10} (particulate matter 10 micrometres or less in diameter) for the SH16/18 case study area, along with nitrogen oxide (NO_x) and sulphur oxide (SO_x) emissions, for which 'isobars' are mapped at specific cut-offs, some of which relate to impacts on human health. Responses of New Zealand ecosystems and components to these are poorly studied, but concentrations across the vast majority of New Zealand are low, being elevated in restricted urban areas where particularly vulnerable, low-fertility (low N) ecosystems are generally rare. Where high emissions and low fertility ecosystems are present, dry or wet deposition of NO_x favours plants that can respond to nitrogen (eg, grasses).

43 https://www.nzta.govt.nz/roads-and-rail/highways-information-portal/tools/air-quality-map/

Figure 2.6 Air quality as average PM_{10} (24 hr) for SH16/18 case study area (orange = 40–50 $\mu g/m^3$; yellow = 30–40 $\mu g/m^3$; green = 20–30 $\mu g/m^3$). These data are publicly available on the Waka Kotahi website.[44]



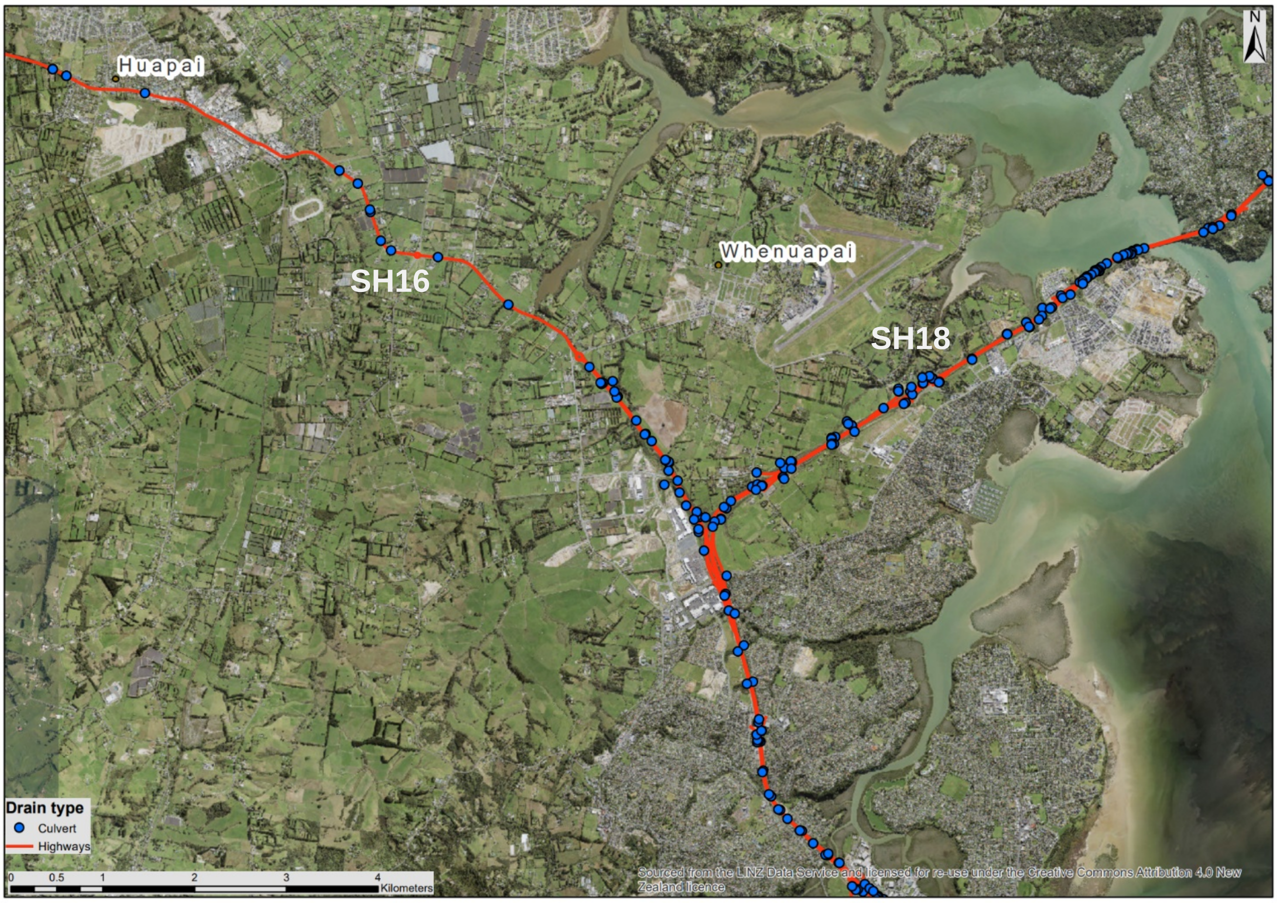
Stormwater

The impacts of stormwater runoff are indicated by locations of bridges and culverts (the latter are mapped in the RAMM database, Figure 2.7). The locations of 'green infrastructure', which includes planted stormwater treatment devices such as swales, bioretention devices, wetlands, and stormwater ponds, are not usually captured in the RAMM database but may be included as 'dam' (12 recorded nationally) or 'permanent silt pond' (10 recorded nationally). Neither are likely to accurately represent the number of such devices. In some cases, individual engineered components within 'drain type' can indicate the presence of green infrastructure – for example, erosion dissipation pad, scour protection, weir, concrete-overflow, and manhole with grate or scruffy (domes). Such components help identify if wetland features, which may appear natural from a visual inspection, are actually part of stormwater infrastructure. These constructed features are likely to receive elevated levels of contaminants and regular maintenance that can remove vegetation and 'reset' ecological values. It is also critical to identify if wetlands are natural or constructed under the Essential Freshwater package (National Policy Statement for Freshwater Management and National Environmental Standards for Freshwater); damaging natural inland and coastal wetlands is a discretionary activity.[45]

[44] https://www.nzta.govt.nz/roads-and-rail/highways-information-portal/tools/air-quality-map/

[45] Interim guidance on the definition of natural wetlands is available at https://www.wetlandtrust.org.nz/wp-content/uploads/2021/04/7-April-21-Exposure-Draft-Wetlands-Definitions-in-the-NPS-FM-and-Freshwater-NES.pdf

Figure 2.7 Culvert locations along SH16/18, with satellite photograph underlay.



Other road data

The RAMM database does not record the locations of wildlife-specific barriers or underpasses. Both are important to identify because they are designed to reduce roadkill of high-value native species. For example, fences to exclude penguins were built along 3.3 km of SH6 where over 100 kororā/little blue penguins had been killed over 5 years to 2013. Anecdotal reports mention few subsequent records of roadkill (Mills, 2013[46]). Penguin underpasses have been constructed in Wellington and Oamaru (on side-roads). These structures would be very useful to add to the RAMM database, as they would immediately identify the presence of high-value species and mitigation of the edge effect of roadkill. Structures to reduce roadkill have included kea gymnasiums (Nicoll, 2018[47]), designed to prevent kea being distracted on roadsides; however, no data are available on their efficacy, and the gymnasium installed at Arthur's Pass was not detected in the case study. Similarly, a fish passage is currently only recorded at five sites in the RAMM database, so was not useful for this project; however, these data could be expected to be included in future given requirements to ensure fish passage through culverts and under bridges.

The final feature that is useful to map when assessing edge effects of roads is Waka Kotahi-administered Crown land parcels that are adjacent to the highway corridor. Waka Kotahi-administered Crown land does not necessarily have significant ecological attributes that require protecting, but management to enhance, mitigate or compensate for edge effects of roads is likely more feasible for Waka Kotahi to control on the

[46] https://www.nzherald.co.nz/nz/penguin-road-kill-passes-100-mark/RAFF5WENAOUNWKFOBBMIJ6IMDM/

[47] https://www.stuff.co.nz/motoring/100321972/roadconemoving-kea-get-gym-to-distract-them-away-from-traffic

land it administers. Such land parcels are most likely to be present in areas with new or designated capital projects. These are discussed in the SH16/18 case study (section 3).

Three important indicators of road edge-effects were not able to be automatically generated and mapped from desktop databases. These are:

1. the width and area of impervious surface to the outer edge of the road seal
2. the 'construction zone' width from which original vegetation and soils are stripped and/or surface affected by excavation or fill (ie, re-contoured surfaces)
3. the 'clear zone' (see section 1.2.2).

The latter disturbance generally severely reduces ecological values for most native New Zealand species and ecosystems, except for particular herbfield and grassland ecosystems (see SH73 case study, section 4). The use of a digital elevation model was investigated to indicate the 'construction zone', as engineered surfaces usually have very even cut and fill slopes that contrast with adjacent landform slopes; however, these data were not particularly useful at the scale of the case studies. This zone was also not consistently able to be defined from aerial photographs or maps because they were masked by regrowth of vegetation. It is critical for new capital projects to map and report these three metrics. The first two metrics could then be linked to research on edge effects such as barriers to movement across roads and vulnerability to establishment of non-native plants. The construction zone is an important indicator of long-term edge effects linked to native habitat quality through controls on rapidity of recolonisation and biodiversity recovery. It could also support calculations of mitigation requirements/offsets at the completion of capital projects, allowing comparison of actual vs predicted footprints.

2.1.1.2 Step 1b: Ecology desktop screen: Identify species, ecosystems/habitat, and spatial locations

The spatial databases listed in Table 2.2 are useful to identify likely biodiversity values of areas adjacent to the road corridor. Some of these databases were updated and collated in a parallel workstream (Price et al., 2021); most are applied at the ~1:50,000 scale. The maps/data layers and their specific use are shown in Table 2.2. An important attribute of the LCDB v5.0, PANZ-NZ and TEC databases is that they cover all of New Zealand, so definitions of classes are consistent at a national scale, unlike regional council maps of significant ecosystems. The polygons or point data that intersect either the 'edge effect 100 or 500 m lines' should be reviewed to identify classes that indicate native biodiversity values are likely to be present (the later field survey is a suitable scale to assess values closer than 100 m). Most larger areas (larger than 0.5–1 ha) of native-plant-dominated ecosystems with high ecological value will be identified using the LCDB, which identifies the dominant habitat based on plant canopy cover; the presence of native animal and fungi species is therefore inferred by presence of native vegetation dominance. LCDB classes with either native or non-native forest canopy should be identified for field checking as the latter may support a range of forest-obligate, 'species-blind' native plants and animals. The presence of such species depends on specific features – for example, coarse wood forming a substrate for invertebrates or fungi; trees with bark that forms suitable hiding crevices or branch structures that enable epiphytes to establish; and the many invertebrates of leaf litter layers.

Table 2.2 Maps and data used to inform a draft edge-effects map of biodiversity values for field verification. All but Significant Natural Area (SNA) layers are publicly accessible.

Map/Data source	Rationale for use
Land Cover Database (LCDB) v4.1 and v5.1[48]	LCDB v4.1 maps the dominant vegetation cover in summer 2012/13. Use to identify the dominant indigenous ecosystems and also the specific ‘Wetlands’ layer to locate these ecosystems. Parts of New Zealand, such as Waikato, have higher-resolution wetland maps that should also be used.
Protected Area Network – New Zealand (PAN-NZ)[49]	This identifies land parcels probably managed primarily for biodiversity outcomes. It includes most land managed by DOC and QEII covenant holders (although it can include open space covenants) among others.
Significant Natural Areas (SNAs) Significant Ecological Areas (SEAs)	SNA and SEA maps are available from some territorial authorities (eg, SH16/18 case study uses Auckland Council SEA layer). Classifications vary between regions; many areas use the Singers and Rogers (2014) classification system, and some areas may be excluded following consultation. New maps are becoming available each year.
Threatened Environment Classification (TEC)[50]	This map uses indigenous plant cover from the LCDB v4.1 as a surrogate for biodiversity and identifies areas that are most threatened due to a combination of small residual area and legal protection.[51]
Biodiversity Atlas	Point records of biodiversity, useful to scan for rare and threatened species and includes ‘research grade’ observations from iNaturalist.
iNaturalist NZ[52]	Point records. The most useful data are ‘research grade’ observations of fungi, invertebrates, and groundcovers that are not recorded in other databases (other than the Biodiversity Atlas); also useful for native plants in areas with non-native plant canopy and to identify local flowering and fruiting times, and sometimes pest plant pressures.
New Zealand Plant Conservation Network (NZPCN)[53]	The NZPCN provides detailed information on New Zealand flora (vascular, non-vascular and fungi), including distribution maps, plant lists for individual sites, and nationally for both indigenous vascular plants (2,414 species) and naturalised plants (2,436 species). New Zealand Botanical Society journals and newsletters also contain plant lists and useful information.

The LCDB ‘wetland’ layer, land managed primarily for conservation, and land identified by regional or district councils as having significant natural or ecological values (SNA or SEA respectively) are likely sensitive ecosystems. Councils identify parks they own or manage in spatial databases (Figure 2.8); parks that have tree or shrub cover (ie, not in mown grass) may have ecological values and should be marked for field checking, even if dominated by non-native canopy. SEAs commonly overlap with parts of city or regional parks. Not all SNAs have high ecological value. In some areas SNAs protect natural landscapes (ie, views).

The TEC has particular value when considering the scale and condition of native biodiversity that may be significant and therefore significantly influenced by road edge-effects. For example, in ‘red zone’ areas that have < 10% of the ecosystem remaining in native ecosystems (such as the Auckland SH16/18 case study), even very degraded, small, and/or linear patches have high value. Identifying these is a priority for field

[48] LCDB v5.0 is available at https://lris.scinfo.org.nz/layer/104400-lcdb-v50-land-cover-database-version-50-mainland-new-zealand/

[49] The current publicly available maps can be accessed at https://ourenvironment.scinfo.org.nz/maps-and-tools/app/Habitats/lenz_prot_areas?m=ZGYwOWVmODB

[50] https://lris.scinfo.org.nz/layer/48282-threatened-environments-classification-2012/

[51] Areas with less than 10% and 20% of original ecosystems are priority candidates for avoidance and added suitable buffering to expand the ‘core’ and protect from damage and weed invasion.

[52] https://inaturalist.nz/

[53] https://www.nzpcn.org.nz/

assessments. In such depleted environments, engineered devices such as stormwater ponds (Figure 2.9) may also have significant ecological value, despite ecosystem values being subsidiary to their role in contaminant retention (and requirement for periodic maintenance that removes plants and sediment).

The LCDB and the TEC are included in the New Zealand Environmental Data Stack, which is a standardised collection of spatial layers for environmental modelling and site characterisation (McCarthy et al., 2021[54]).

The NZPCN and iNaturalist generally provide more accessible and useful information than the Biodiversity Atlas (Table 2.2). Both the NZPCN and iNaturalist allow searching for individual species of interest and provide weblinks with useful information about species, including common names, photos and monthly frequency distribution of observations. For example, the SH16/18 case study included an iNaturalist observation of forest gecko on an adjacent road, and records of the two less-common weeds Moreton Bay fig (in a tōtara) and Japanese aralia, which could then be looked for in the field assessment. In some areas, such as Arthur's Pass National Park, species lists are provided (Figure 2.15). iNaturalist also includes 'Projects' that can also be useful – for example, Arthur's Pass observations are linked to a project called 'Invasive plants of Australian and New Zealand mountains', and the 'Roadkill New Zealand' project contains nearly 1,000 observations of 93 animal species.

Both the Biodiversity Atlas and iNaturalist have the greatest value in publicly accessible areas such as parks and parts of the DOC-managed land near roadsides where parking and/or walkways are present (Figure 2.14). If roadsides are not accessible (eg, along most of the SH16/18 case study area), there are few observations. Both databases may be useful to flag species that are not necessarily linked to habitats dominated by native plants, such as lizards, many dead-wood insect and fungal specialists, some birds, and open-ground specialists such as some native bees and tiger beetles. The Biodiversity Atlas does not include common names or a mapping function, so it is more time-consuming to use.

Figure 2.8 SH16/18 case study area showing Auckland Council delineated SEAs (dark green) and Council parks (light green) with waterways (blue) and culverts (purple). Screenshot from publicly accessible Auckland Council database.[55]

[54] https://dx.doi.org/10.20417/nzjecol.45.31

[55] https://www.tiakitamakimakaurau.nz/conservation-map/

Figure 2.9 **Map showing SH16 and SH18 watercourses, wetlands and riparian vegetation. The purple 'Open water' wetlands include the bigger stormwater ponds.**[56]

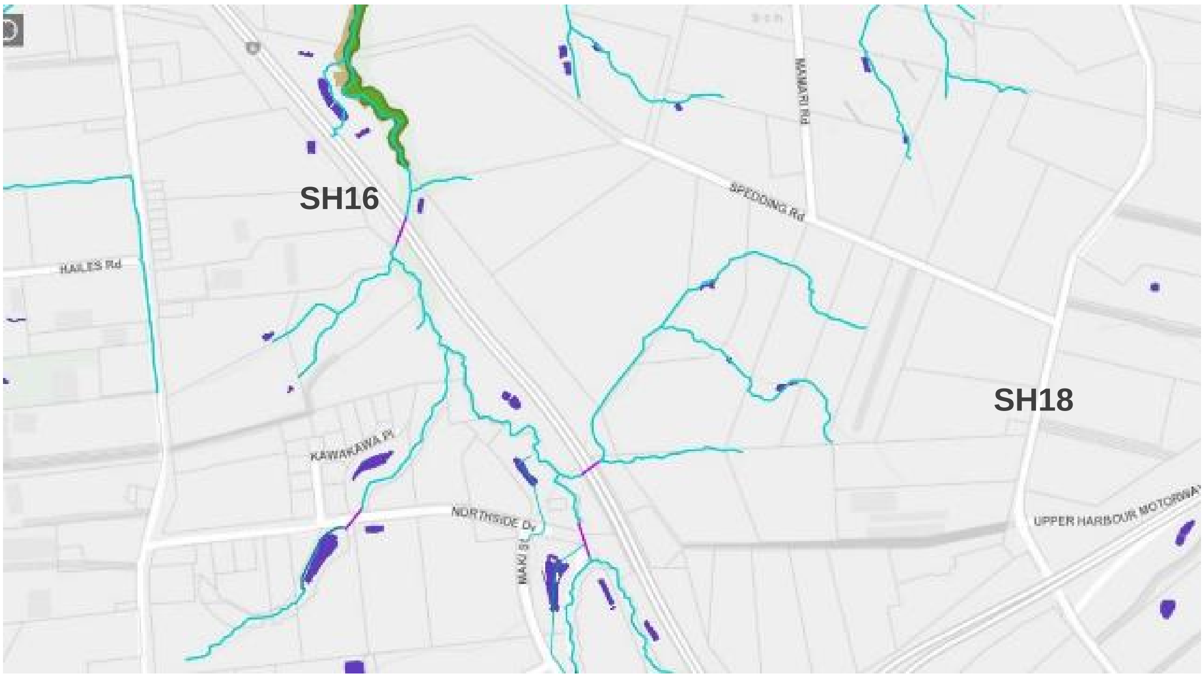
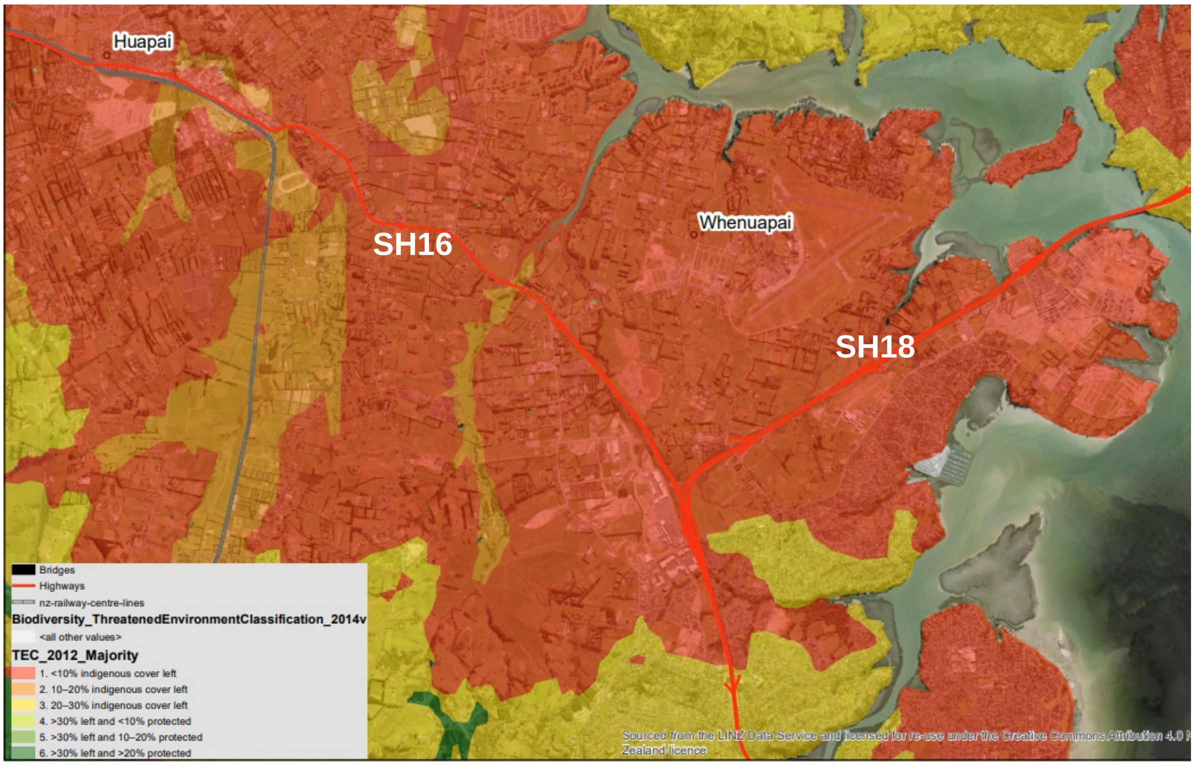


Figure 2.10 **Map of SH16/18 case study area with TEC overlay showing that the majority of the area has the highest threat classification (coloured red), indicating less than 10% of the original ecosystems remain.**



[56] The website https://www.tiakitamakimakaurau.nz/conservation-map/ uses a modified Singers and Rogers (2014) classification and is primarily used to guide Auckland Council's biodiversity/biosecurity work.

Figure 2.11 Screenshot of iNaturalist web page showing two 'research-grade' records of threatened native species adjacent to SH16 (extracted May 2021). Both would trigger a field check.

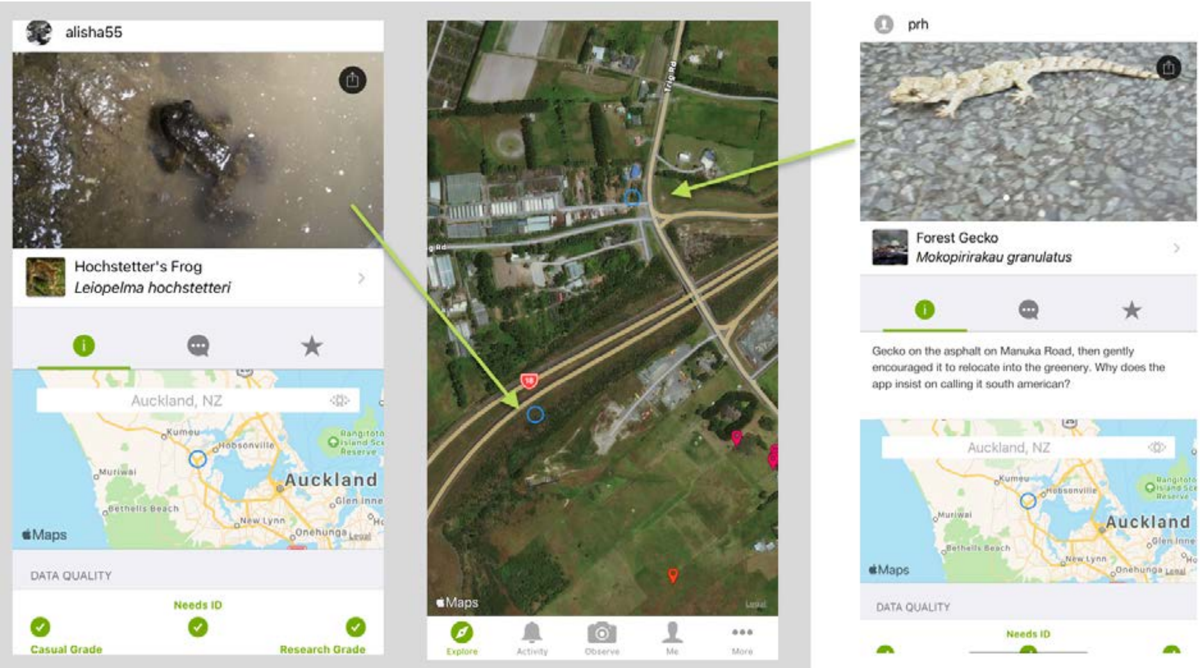


Figure 2.12 Screenshot of iNaturalist web page showing locations of observations in Arthur's Pass National Park, many of which are alongside SH73 (extracted May 2021). Green = plants; blue = animals; pink = fungi.

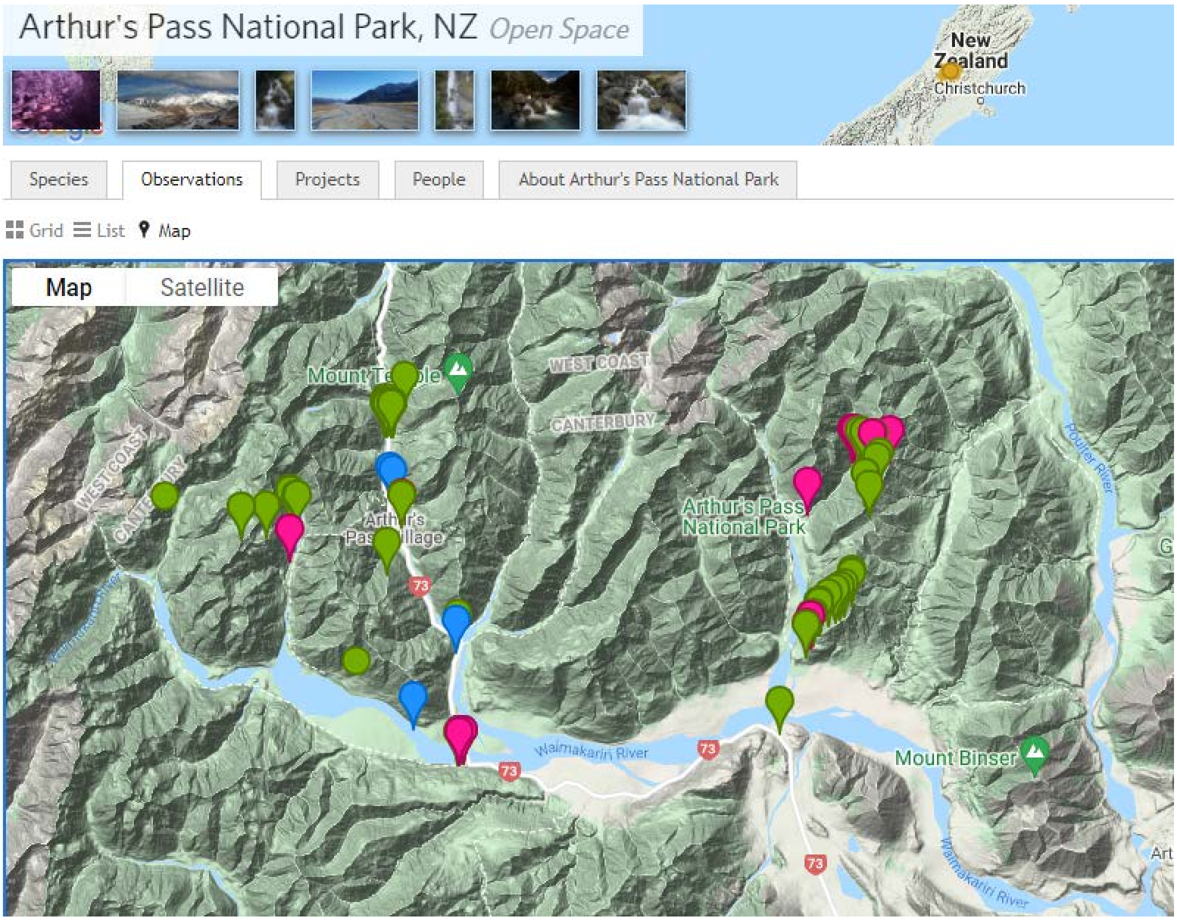
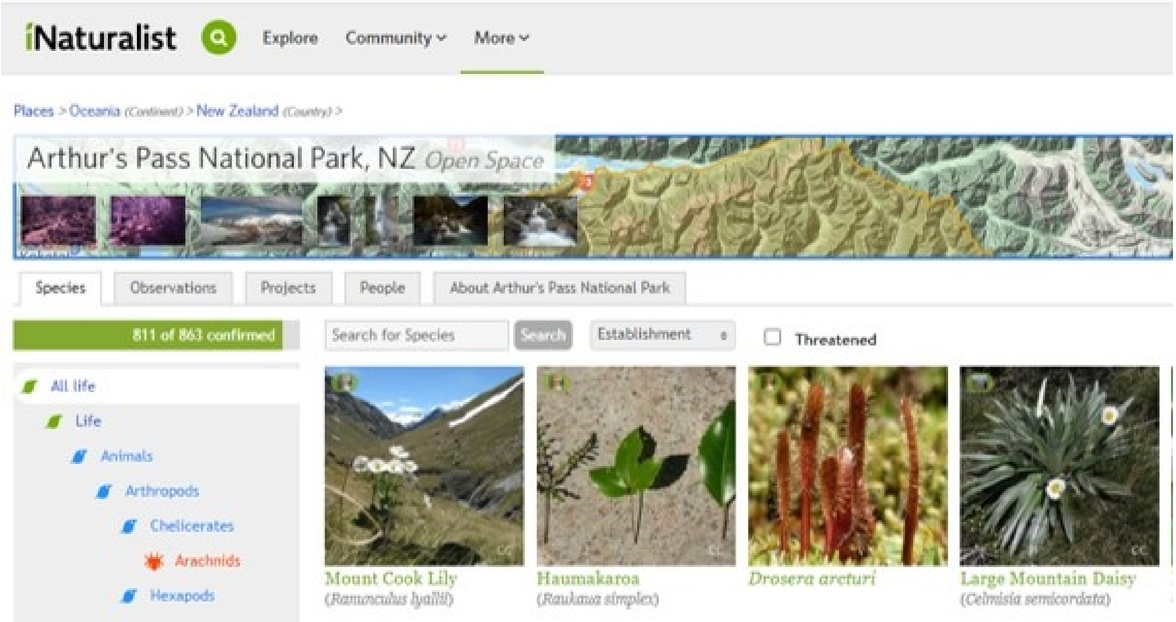
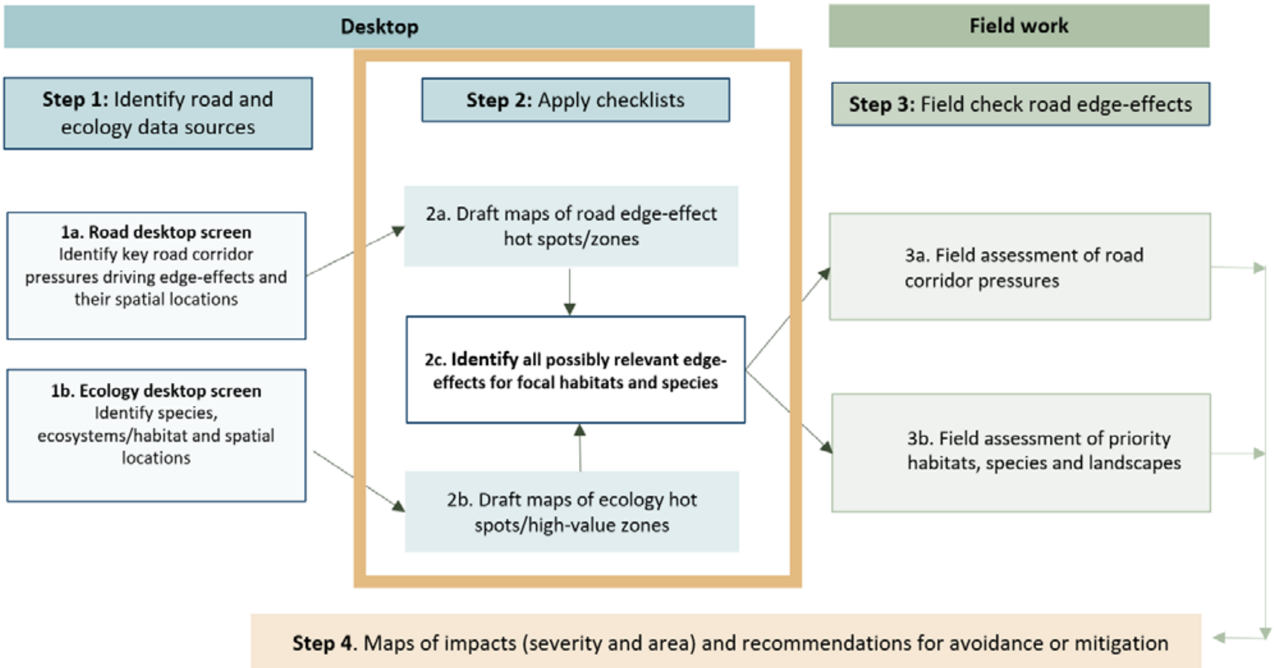


Figure 2.13 Screenshot of iNaturalist web page showing the Project 'Arthur's Pass National Park' (extracted May 2021). The website provides readily accessible information on different plant, animal and fungal species recorded by users.



2.1.2 Step 2: Use checklists to categorise road edge impact

Figure 2.14 The road edge-effects assessment method, highlighting Step 2.



Checklist: Edge effects

In Step 2, road features from the Waka Kotahi road corridor map (and road data) are reviewed alongside the spreadsheets of road edge-effects (Table 2.3 and Table 2.4) to identify and highlight road features and pressures with high negative or positive edge effects. The purpose of the checklist is to highlight the breadth of road edge-effects, as many are commonly underestimated in New Zealand ecological assessments. Factors that moderate or exacerbate edge effects are identified in the checklist. These are used in Step 4 to help assessors identify actions that avoid an edge effect altogether, or moderate/mitigate edge effects. This also prioritises areas of the transport corridor where edge pressures are most important to address through road design using the effects management hierarchy.

The checklist groups road edge-effects into seven classes, although some effects overlap:

1. Noise and vibration (from roads)
2. Light (from roads)
3. Stormwater runoff peak flow, volume, contaminants and attenuation (from roads)
4. Hydrology (from roads and ecology)
5. Emissions and heat (from roads)
6. Habitat modification, including fragmentation (from ecology)
7. People factors: road users and neighbours (from land cover)

Checklist: Vulnerability of biodiversity to road edge-effects

In this step, point biodiversity data are reviewed (Table 2.3) for native species within the buffer zones and their locations marked. Point data are searched for records of pest plant species. Pest plant species are generally identified in the relevant regional pest plant management plan/strategy. Weedbusters and DOC environmental weeds lists (Howell, 2008[57]) should also be consulted. Management plans for national parks and some reserves will also generally include information on pest plant species. These lists will be used in Step 3.

Working through the spreadsheet in Table 2.4 helps highlight the biodiversity components (ecosystems and species) that are more sensitive to negative edge effects, and where these intersect with high negative edge pressure. Available species-specific information should be used (eg, New Zealand bats, pāteke/brown teal, peripatus) noting species and ecosystems conservation priorities change over time, both due to threat classifications being updated[58] and land use change (eg, plantations being established or urban expansion occurring) or management changing (eg, landscape-scale pest control such as wilding pine removal).

[57] https://www.weedbusters.org.nz/what-are-weeds/weed-list/ and https://www.doc.govt.nz/globalassets/documents/science-and-technical/drds292.pdf

[58] https://www.doc.govt.nz/about-us/science-publications/conservation-publications/nz-threat-classification-system/

Table 2.3 Spreadsheet of potential road edge-effect pressures and modifiers or exacerbators of the pressures. Roading stages are construction (C), defect liability (DL), and operations and maintenance (O&M).

EDGE-EFFECT	C	DL	O&M	MODIFIER	EXACERBATOR
Contributing feature	*** relevant ** largest effects**			**(decreases severity or scale of effect)**	**(increases severity of effect)**
NOISE and VIBRATION					
Modelled dB $L_{Aeq(24)}$ map	na	*	**	high variation over 24-hr period may mean impacts at night are reduced	noise during the period that vulnerable fauna of high value are active
Background noise	*	*	**	high noise (urban) or white noise (surf, river rapids, windy sites with plants that create noise – eg, trees/flax)	low-noise environment (conservation area; much farmland, especially at night)
Vehicles/day	*	*	**	high proportion of cars	high proportion of trucks
Road surface	**	*	*	smooth or specified as generating low noise	coarse chip, unsealed roads
Road geometry	*	*	*	gentle grade and corners reducing acceleration and braking	sharp corners, steep grades, intersections, one-lane bridges, passing lanes
Traffic speed km/hr	*	**	**	reduced speed zone, which may be applied at times or seasons when target fauna are vulnerable – eg, during breeding, fledging, or at night (links to reducing roadkill of native birds)	100 km/hr or open road speeds
Traffic pattern	**	*	*	quiet times (nights, seasons) that align with key activity of native species (breeding, dispersal, local food abundance)	traffic peaks when species are vulnerable
Noise attenuation	na	*	*	noise-absorbing barriers, bunds, cut faces treated to attenuate noise (not smooth), dense and tall vegetation	reflective surfaces such as cut rock batters and solid barriers, water
Noise-generating features	*	**	*	smooth surfaces; consider features of bridges that can moderate noise detected under the bridge	bridge expansion joints, rumble strips, judder bars or corrugated surfaces on gravel roads, passing lanes (areas of sharp acceleration or braking)
Surfaces adjacent to the road	*	*	*	dense forest/shrubland that absorbs and attenuates noise	water and open space (pasture, tussock) that allow sound to travel; water can reflect noise
Topography	*	*	*	road incised, or cut reduces ‘uphill’ noise spread	roads on flats, especially adjacent to lakes or braided riverbeds; elevated roads (eg, where fill slopes are present); where a road passes through a constrained landform such as a long valley, noise can move along the valley

EDGE-EFFECT	C	DL	O&M	MODIFIER	EXACERBATOR
Contributing feature	*** relevant ** largest effects**			**(decreases severity or scale of effect)**	**(increases severity of effect)**
Climate	*	*	*	mainly clear skies allow noise to disperse (but travel further)	fog and cloud can 'trap' noise; prevailing down-wind areas are noisier than prevailing upwind areas
LIGHT					
Light spread – road assets	*	*	*	shielded streetlights, barriers that block headlight spread including vegetation (when dense and tall enough)	tall lights, no shielding, no vegetation, many lights
Light spread – vehicles	na	*	*	cars, straight roads	trucks (higher beams travel further and tend to have more lights)
Light frequency/colour	*	*	*	orange/yellow (sodium) streetlights	white/blue streetlights, but effects are also species-specific
Light intensity, flicker	*	*	*	dimmed, low flicker streetlights	bright streetlights that flicker at species-specific rate
Duration	*	*	*	controlled streetlights (using sensors, dimming, on/off)	all night, all seasons
Background light	*	*	*	bright lights (urban areas, industrial areas)	dark background (eg, dark sky reserve), isolated lights
Screening of sensitive sites	*	*	*	forest/trees/vines between sensitive site and light source	no shielding and potential for reflecting (eg, waterway/wetland/coast)
Proximity of ALAN to vulnerable fauna	*	*	*	vulnerable fauna distant ~1 km or fauna have small range (moths)	vulnerable fauna close to road ALAN (unscreened) or fauna have large range (eg, petrels/shearwaters nesting on land)
Topography	*	*	*	road incised (or cut/fill), hills	road elevated/flat or in a valley
Climate	*	*	*	dry climate/predominantly dry roads	high frequency of rain days – wet roads increase reflectivity
RUNOFF					
Vehicles/day	na	*	**	few vehicles and mainly light vehicles	high numbers of heavy vehicles, all state highways, primary arterials and roads > 10,000 vehicles/day under Auckland Unitary Plan, industrial and port areas
Road accidents/spills frequency, type	*	*	**	accidents due to road characteristics (eg, separated lanes and gentle corners, lack of ice, low heavy-vehicle traffic) are rare	accidents (eg, spills of fire-fighting foams, petrochemicals, milk) are common
Adjacent land use	na	*	*	low-intensity farming, natural areas such as forests and wetlands	ports, industrial, light-industrial, aggregate or landscape supply activities have higher potential for contamination due to higher proportion of heavy vehicles and/or high impervious surfaces)
Road surface	*	*	*	permeable (reduces runoff), low friction (reduces tyre wear) surface	impervious, rough surface
Road geometry	*	*	*	gentle grade and corners	sharp corners, steep grades, roundabouts, intersections

EDGE-EFFECT	C	DL	O&M	MODIFIER	EXACERBATOR
Contributing feature	*** relevant ** largest effects**			**(decreases severity or scale of effect)**	**(increases severity of effect)**
Road width/ impervious surface	*	*	*	minimum impervious surface	high impervious surface
Road maintenance	na	*	**	sweeping, catchpits to remove sediment	herbicides used in drains/water tables; grit spread in winter (which adds sediment)
Road margins	na	*	**	stable road shoulder	eroded margins, drains generating sediment
Passive runoff attenuation	**	**	**	runoff filtered through plants and soil (swale or verge) 'at source'	kerb and channel, discharges direct to surface water without passing through soil and plants
Active runoff attenuation	**	**	**	wetlands, swales, proprietary devices	no formal treatment
Earthworked (rehabilitated) root zone	na	**	**	root zone depth, surface microtopography and leaf litter/mulch layers similar to natural ground	shallower root zone with smoother surface and low litter layers increasing runoff and decreasing moisture storage
Climate	*	*	*	high frequency of low-to-moderate rainfalls; cool; low moisture deficit	dry, hot, and/or large seasonal moisture deficits
Water table maintenance	na	**	**	vegetated swale, shallow water table	deep drains that are periodically physically and chemically cleared of vegetation
Runoff discharge to watercourse	*	**	**	dispersed, spread over large area	concentrated at few discharge points, poor mixing causing water quality barriers
Peak and volume change	*	**	**	attenuated (eg, stormwater wetlands)	negligible attenuation
HYDROLOGY					
Extent of cut and/or fill	*	**	**	negligible cut/fill	large cut/fills intersecting large aquifers in permeable areas or blocking water flows (surface or subsurface)
Impact on water table in root zone	*	**	**	narrow draw-down zone, water table below influence of root zone	wide draw-down zone; soils with perched water tables or near-surface water tables; many wetlands
Impact on ground water	*	**	**	deep, isolated water table; impervious layers	shallow water table; highly permeable layers in small catchments
Soil and geology	*	**	**	permeable soils that facilitate infiltration into soil and underlying subsoils, hence reducing runoff	impervious soils; wetland soils with near-surface water tables
Aspect	*	*	*	south and east, shaded	north and west (ie, exposed to high temperature fluctuations)
Vegetation vulnerability	*	**	**	young vegetation with wide drainage tolerances	old trees with broad canopy; drought-tolerant herb fields and low-shrubland
Climate	*	*	*	temperate, low moisture deficits	high or seasonally high moisture deficits

EDGE-EFFECT	C	DL	O&M	MODIFIER	EXACERBATOR
Contributing feature	*** relevant ** largest effects**			**(decreases severity or scale of effect)**	**(increases severity of effect)**
Impact of adjacent land use	*	*	*	unmodified adjacent hydrology with natural ecosystems	land drained; land altered by irrigation/hydrology
Stream flows	*	*	*	no change to hydrology	road changes the area, duration or frequency of flood/inundation (this is usually required to be controlled for specific rainfall events in newer capital projects)
HABITAT MODIFICATION, LANDSCAPE EFFECTS AND FRAGMENTATION					
Remnant ecosystems in 500 m buffer	*	*	*	remnant ecosystems and plantation forest absent and unlikely in future	small remnants with large edge effects or continuous native ecosystems that are otherwise unfragmented
Edge ecosystems	*	*	**	native edge ecosystems common and able to be sustained along road corridor; linear ecosystems fragmented	edge ecosystems uncommon; continuous edges present that define flight paths/feeding areas (estuaries, riparian areas, forests)
Critical ecotones/ ecosystem connections	*	*	*	absent or constructed	present and used by native animals
Road corridor habitat	*	**	**	minor component of landscape-level habitat for native species	native habitat confined to narrow road corridor; a depauperate landscape with few or isolated native species or ecosystems
Native seed sources, regrowth, spread along corridor	*	*	*	present, pollinators and spreading agents present, and native plants can exclude/smother weeds under current management (eg, mowing height and frequency)	depleted, fragmented or present only for limited seasons (eg, not in breeding season)
Plant growth rates	*	*	*	fast-growing native species present that are competitive with non-native plants	slow-growing native plants
Road impact on drought/drainage	*	*	**	minimal impact on drought or drainage status (eg, minimal cut or fill, slowly permeable soils with slow lateral permeability, or very rapid permeability)	tall cuts that intercept water tables so dry out edges; fills that block water flows and increase anaerobic conditions
Roadkill potential – non-native animals	*	*	*	low density of vulnerable non-native animals	high density of roadkill, or roadsides providing habitat (eg, dense shelter belts for passerines) or food (eg, mown grass for rabbits, hares); features that concentrate animals (eg, bridges, impassable cuttings that ‘channel’ animals to crossing points, roads through wetlands)
Roadkill potential – native animals	*	*	*	road does not dissect natural ecosystems; adjacent areas not managed for conservation	vulnerable species and vulnerable populations present (eg, roads through forests with land-snails); areas with high non-native roadkill (eg, rabbits in Otago) and abundant native scavengers such as kāhu/harrier hawks, pūkeko and maybe weka

EDGE-EFFECT	C	DL	O&M	MODIFIER	EXACERBATOR
Contributing feature	*** relevant ** largest effects**			**(decreases severity or scale of effect)**	**(increases severity of effect)**
Accessibility of road for animals	*	*	*	barriers prevent access to vulnerable species (eg, penguin fences; roadside water tables for some species)	no barriers to access, mobile species present that may seek warm, open road surfaces in cold weather
Potential for ecological traps along road	*	**	**	ditches, culverts, catchpits, soil noise walls treated to either exclude vulnerable fauna or allow their passage (eg, kiwi exclusion grates, culverts able to be used by pāteke)	vulnerable fauna and traps or habitat present (eg, dense roadside vegetation in farmland with little similar vegetation can provide habitat for kiwi and weka)
Air turbulence created by vehicles	*	*	*	turbulence does not reach natural ecosystems containing vulnerable animals (eg, flying insects, small birds)	light species vulnerable to turbulence, and attracted to edges (eg, butterflies feeding on flat weeds in sprayed or mown strips)
Unvegetated width (includes road shoulder, dish drains)	*	**	**	< 1–2 × plant height (minimising light, heat, microclimate effects)	cleared area > 1–2 × canopy height, especially where ecosystems are vulnerable to edge effects
Habitat ‘gap’ width and extent	*	*	*	gaps non-limiting and/or limited in extent along road	gaps ‘wide’, over ‘long’ distances, which are ecosystem, structure, and species specific (and may interact with road-derived noise and light)
Width of tree ‘gap’	*	*	*	trees absent (naturally), or no gap and trees resilient to stress (exposure, drought)	wide gap, gap is at different elevations, trees susceptible to further dieback
Width maintained by mowing/herbicide (includes drains)	*	*	*	narrow; tree canopy extends over mown edges and road, especially on north side so road is shaded	wide; road and edge exposed to afternoon sun
Mowing height, effect and frequency	na	*	*	no mowing, or native plants below mowing height and mowing supresses competing grass	mowing creates bare surfaces that favour non-native plants
Herbicide area and width	na	*	**	small, targeted and not in areas transporting water	herbicide area around marker posts, barriers, signs, culverts and/or water tables is greater than minimum requirement
Herbicide selection	*	*	**	glyphosate only, or targeted application method (cut/paste, wick boom) or broadleaf where natives are monocots (or vice versa)	residual, broad-spectrum herbicide applied, damaging penetrants or surfactants used as additives (particularly to glyphosate)
Construction footprint	*	*	*	soils intact, coarse wood retained (only plants removed)	soils stripped or buried; coarse wood removed
Construction impacts outside removal zone	*	na	na	impacts restricted to sites with negligible ecological values	adjacent areas covered with gravel/fill or stockpiles, compacted by vehicles, slopes stabilised using high density of non-native species (eg, hydroseeded pasture)
Vulnerability of remnant habitat to weed invasion	**	**	**	low; native ecosystems resilient (dense, tall, few gaps)	high

EDGE-EFFECT	C	DL	O&M	MODIFIER	EXACERBATOR
Contributing feature	*** relevant ** largest effects**			**(decreases severity or scale of effect)**	**(increases severity of effect)**
Non-native and pest plants in road corridor	**	**	**	absent	present – eg, areas hydroseeded with N-fixing species, landscaping includes 'weedy' species, long-lived seed banks of non-native species present (gorse, broom, some *Juncus*)
Non-native/pest plants able to spread along corridor	*	*	*	pest plant species absent and management excludes suitable establishment sites; palatable pest plants browsed in adjacent landscape (eg, farmed landscapes)	pest plants present, but absent in adjacent areas (agricultural landscapes); bird-dispersed pest plants (prunus, privets, spindleberry, loquat)
Non-native/pest plants able to spread along water tables	*	*	**	species absent, water tables absent or limit spread (eg, absence of kerb and channel)	vulnerable with drain maintenance (eg, spreading fragments of alligator weed, seed of Himalayan balsam)
Pest plants spread by mowing/herbicide	*	*	**	species absent in adjacent land, edges unfavourable for spread	present – eg, grasses, agapanthus and Spanish heath (herbicide resistant), tradescantia or ivy (fragments), montbretia (bulbs), or seeds (agapanthus, many grasses)
Presence and impact of non-native herbivores	*	*	*	non-native herbivores controlled or absent	Active, supressing regeneration and regrowth of native plants
Predator habitat or access along road corridor	*	*	*	predators not present (or being controlled in adjacent landscape); barriers present	cats or possums present (these are most likely to move along roads), mice in verge (cover)
ROAD USERS AND NEIGHBOURS					
Neighbouring land is managed for native biodiversity (eg, PAN-NZ)	*	*	*	land not managed for conservation, low ecological values	adjacent landscape managed for conservation (eg, predator and weed control, high ecological values)
Co-location of other linear infrastructure	**	**	**	absent	railway or transmission lines, water races or drainage schemes present
Neighbouring land verge management of highway	*	*	*	sympathetic management, remote areas; low-intensity farming	peri-urban with high driveway densities, intensive agriculture can increase disturbance (mowing/herbicide/drain clearance)
Neighbouring land: irrigation	*	*	*	irrigation using low-drift emitters, non-effluent spray and/or non-dryland environment	in drylands, having irrigated land adjacent increases value of remnant road verge
Neighbouring land: weed sources onto road corridor	*	**	**	stable land management in pastoral agriculture	forestry areas near harvest, actively eroding areas, new land uses that include weed species (olives, pest pines, Russell lupin) or new landscaping (agapanthus)
Illegal dumping or planting (plants, animals)	na	*	*	absence of 'fly-dump sites', road shoulders do not allow vehicle stopping	close to urban areas, pullovers with dump-drops and secluded areas, house entrances (planted with common garden weeds such as agapanthus, hydrangea, rhododendrons and red-hot poker)

EDGE-EFFECT	C	DL	O&M	MODIFIER	EXACERBATOR
Contributing feature	*** relevant ** largest effects**			**(decreases severity or scale of effect)**	**(increases severity of effect)**
Gross pollutants (litter, plastics)	na	*	*	low traffic density	high traffic flows and near roadside service areas with fast food outlets (within about 15 minutes' drive)
Increased fire risk	na	*	*	humid, moist environment and/or low fuel load and flammability	rest areas with potential camp sites and fuel trees (for firewood), long grass or gorse verges in dry climates, tussock lands
Habitat disturbance from access to edges	na	*	*	road shoulders do not allow vehicle stopping	rest areas, pullovers with access to waterways, coastal areas, vulnerable alpine environments, sites with views (especially views with weeds that may be transported such as Russell lupin)
AIR EMISSIONS AND WIND					
Vehicles/day	*	*	*	mainly cars and low vehicle numbers	high proportion of trucks and diesel vehicles
Road surface	*	*	*	smooth	unsealed roads (dust)
Embodied heat	*	*	*	vegetation, reflective (concrete) and shaded surfaces	dark surfaces with high heat absorption exposed to sun (pm); rock – materials that absorb heat, then radiate it, orientation matters
Low-humidity/wind	*	*	*	open landscape with low natural humidity; dense edges	tall rain forest adjacent with open edges that allow wind penetration, especially if a small patch (less core) or not buffered; exacerbated by wind funnelling along hot roads (orientation)
Road 'gap' geometry, continuity, and aspect	**	*	*	narrow, short gaps avoid wind tunnel effect	long continuous gaps extending to features that create wind funnels into vulnerable areas
Attenuation by edges	*	*	*	high – dense, fine, continuous vegetation	low – contaminants trapped under canopy, calm conditions
Adjacent cover	*	*	*	dense buffering edge vegetation	water, open space, smooth cut faces
Topography	*	*	*	road raised or on hill slope	road incised or in a valley with low wind/circulation such as temperature inversion basins
Background air quality	**	**	**	air quality dominated by non-road emissions	air quality low in contaminants or road load triggers threshold for adverse effects

Table 2.4 Features indicating vulnerability of native biodiversity to road edge-effects. Note: If species-specific information on road mitigation is available, that information should be used.

Feature of biodiversity present	Resilient/low vulnerability	Medium vulnerability	High vulnerability
Environment status (TEC)	common environments able to be replaced within 25 years		highly threatened environments, or not replaceable within 25 years
Species status (www.doc.govt.nz conservation status reports)	not threatened		nationally vulnerable or at risk
Distribution	widely distributed, location not at edge of species distribution		at edge of species distributions or isolated species
Home range	small depending on available habitat (pīwakawaka/fantail, lizards, many invertebrates)		large and likely to intersect road (kiwi, large carabid beetles, bats)
Breeding rate, longevity	fast breeding rate (many offspring at a young age/precocious), short-lived		low breeding rates (few offspring and long time to maturity), long-lived
Dispersal, including along a road corridor	Recruitment not limited by pollination, dispersing agents or predation		recruitment limited by pollination (lack of outcrossing or pollination agent), dispersing agents or predation
Vulnerability to fragmentation/road 'gaps' as barriers	highly mobile (eg, strong fliers such as tūī, kererū), insensitive to artificial light or noise		avoid disturbance, unable or unwilling to cross roads, poor fliers (robins, whiteheads)
Vulnerability to fragmentation/roads as barriers	tolerant of highly variable, patchy habitat, cosmopolitan		intolerant of highly variable habitat (patchiness)
Specialist of edges, cut banks – moderate-high moisture stress and exposure	adapted: some epiphytes such as rātā, mistletoes, ferns, trap door spiders, native bees, some tiger beetles		unable to use such habitats, vulnerable to moisture stress and exposure (require deep, moist leaf-litter layers, forest 'core', peripatus)
Use of road corridor features for habitat	flexible or adapted to built structures: bridges (nesting swallows), culverts (orb spiders)		avoids road features (deterred)
Animal response to threat (light or vehicle approach)	fast, rapid movement, flight		slow movement (Powelliphanta snails), freeze behaviour with threat such as vehicles (pāteke)
Animal attracted to roadkill	not attracted	attracted but opportunistic	strongly attracted and seek roadkill – kāhu/harrier hawks, pūkeko
Animal response to vehicle noise, communication method	visual		sound or vibration in similar range as vehicles to establish territories
Animal avoids predators; locates prey using sound or vibration	no		solely
Animal attracted to heat/warm surfaces	no		some lizards, maybe fur seals

Feature of biodiversity present	Resilient/low vulnerability	Medium vulnerability	High vulnerability
Response to artificial light at night (constant and intermittent)	not attracted		attracted – eg, moths, huhu, petrels, and nocturnal hunters of attracted invertebrates (bats, ruru, spiders) – or light stops feeding behaviour, or light is a cue for movement (aquatic insects)
Animal use of grass/mown road verge for food or shelter	actively avoided	low/opportunistic	attracted – eg, fresh grass or mice for pūkeko, flatweed and brassicas for cabbage white butterflies
Vulnerability to mouse predation and grass verges present	not vulnerable		vulnerable (fruit or animal – eg, ground invertebrates, some lizards)
Uses roadside water tables/drains/ponds as habitat	specialist or generalist that can tolerate warm water, contamination (tuna/eels)		sensitive aquatic species requiring 'clean', cool receiving water, road discharge is high proportion of flow in summer
Animal moves on land up riparian corridors and from wetland to wetland	no movement	occasional or opportunistic movement	moves frequently on a daily cycle (brown teal, pūkeko)
Animal vulnerable to ecological traps	abundant alternative habitat away from roads, does not enter road corridor		little suitable habitat away from roads, or enters road corridor and is vulnerable to desiccation (Powelliphanta)
Animal responsive to road underpasses, over-passes or flight 'lifts'	will use suitable structures (eg, penguins, brown teal, cormorants flying higher over bridges)		no structures shown to be successful
Use of established 'routes' through landscape	low fidelity to routes		high fidelity to edges and routes – eg, bats along edges, cormorants up rivers (hit on bridges), penguins to nesting areas
Coarse wood, old/large trees (epiphytes, cavities)	not requiring		obligate, especially vulnerable where features are sparse (bats, perches by water for shags, tree crook epiphytes)
Plant species tolerance of hydrological change, especially with drainage changes	species adapted to drought stress/fluctuating water tables		perched water tables, shallow aquifers, trees nearest edges of cuts or fills
Vulnerability to plant competition under mowing regime	advantaged by mowing regime (some herbs)		slow to recover from mowing, slow-growing or taller plants

Step 2a: Draft maps of road edge-effect hot spots/zones

Road data in polygons identified in Table 2.3 that intersect the 100- and 500-m road edge lines are collated and then reviewed.

Step 2b: Draft maps of ecology hot spots/high-value zones

All polygons managed for biodiversity outcomes and all polygons with dominant native cover are collated. TEC polygons with < 10% and < 20% ecosystem remaining should be highlighted along with all wetlands and polygons with non-native dominant cover that need field checking for potential native biodiversity values (ie, permanent woody vegetation and low-productivity grasslands in dry regions). Aerial photographs are useful to identify such areas of road corridor that may support biodiversity that is too small, sparse (eg, low tree cover) or sub-dominant to be detected in the national LCDB maps. This is particularly important when biodiversity is poorly represented in the surrounding landscape. These small or sparse areas may be priorities for enhancement by buffering to increase 'core' and/or reduce negative edge effects.

Step 2c: Identify all possibly relevant edge effects for focal habitat and species

The maps showing road features likely to affect species and habitats, and the locations of those species and habitats produced as a result of steps 2a and 2b respectively, are combined to identify road edge areas (or polygons) and point locations with preliminary edge-effect values: positive, non-significant, moderate negative or highly negative. This effects value is based on threat classification, sensitivity to edge effects and moderating or exacerbating features and pressures of the road corridor. In most locations there will be negligible information about key biodiversity groups such as invertebrates, soil organisms or fungi.

The two case studies showed that the largest and most disparate edge effects were generated by four factors: habitat modification/fragmentation, stormwater, noise, and light. However, roadkill is likely to have adverse effects at a population level for some native species in specific locations of New Zealand, and it needs to be assessed separately where vulnerable native species and habitats are present. The vulnerability of some large, vulnerable native birds to roadkill is summarised in infographics in Appendix A (Figure A.5, Figure A.6), and factors affecting vulnerability of fauna are summarised in Table 2.5 below and in an infographic in Appendix A (Figure A.7).

Table 2.5 Summary of factors affecting the vulnerability of fauna to roadkill

Factor affecting vulnerability of fauna to roadkill	Example of species
Walk across roads	Kiwi, pāteke, weka, penguin, snails, pūkeko
Attracted to artificial light	Ruru, Westland petrel, bats, many nocturnal insects
Vulnerable to desiccation/low humidity/high light	Snails, many leaf litter insects (peripatus), some lizards
Attracted to road surface	Fur seals, some birds, insects laying eggs on 'water'
Attracted to roadkill	Harriers, pūkeko, weka, some seagulls
Communicate using calls	Small birds (pīwakawaka/fantail, tūī, korimako/bellbird)

While reasonable data on edge effects of New Zealand roads from habitat modification related to non-native plants and road stormwater runoff are available, in most other areas a key limitation to assessing other edge effects is our lack of knowledge of the biology of many native ecosystems and native species. This includes most native birds. Lack of data on the effect of vehicle noise severely limits the ability to assess ecological impacts. Likewise, there are no New Zealand studies on the impacts of lighting on land birds. The following 'rules of thumb' for edge effects are proposed, based on literature review, until a stronger evidence base is present for New Zealand species and ecosystems (section 5.3 recommends priorities and methods to deliver this evidence base).

- Noise: 55–59 dB edge modelled, strongly linked to AADT. Where background noise is low, default to 50 dBA (although this is not currently modelled by Waka Kotahi).
- Light: the distance from which light is visible at ground level. Lower impact with reduced proportion of blue light spectrum (Frith, 2021).[59]
- Habitat gaps in forested landscapes: 110 m[60] with target for low effects being the road tree 'gap' being less than twice the height of adjacent trees.
- Habitat modification: 'construction zone width'. Lower ecological value in all areas cleared of vegetation and soil during construction (cut or fill and ancillary areas) than equivalent undisturbed areas. These are generally vulnerable to weeds, altered hydrology reduced leaf litter layers, and absence of coarse wood.
- Habitat modification: 'physical disturbance zone'. Reduced ecological values likely < 2 m from edge of high-disturbance zone in grassland, < 5 m from edge in shrubland, and up to 50 m for edges through forest, depending on buffering and hydrological changes. This zone includes the bulk of changes to microclimate. The physical disturbance zone in wetlands is site specific and varies from upstream to downstream.

Some species are highly likely to have adverse responses to noise and/or light levels lower than these rules of thumb. More sensitivity could be delivered by replacing 24-hr average values with noise at ecologically meaningful times of day or night (for nocturnal or crepuscular species), or seasons. Such data would inform mapping of 'reverse-sensitivity zones' for light and noise, similar to those currently used by Waka Kotahi to reduce impacts on people.

Features of transport corridors that are associated with increased sensitivity to road edge-effects include the following, some of which are summarised in two infographics in Appendix A (Figure A.3, Figure A.4).

- Where roads are the dominant cause of noise and light (sparsely populated areas).
- Bridges and culverts, especially where bridges do not maintain natural flood zones and continuous vegetation underneath them.
- Where roads lead to mortality of mature trees (especially in areas with cavity users and epiphytes). This could occur if a road through a stand of wet forest increases sunlight, changes drainage patterns, etc, increasing forest drying and drought vulnerability.
- Where road cuts or fills are over ~3 m height (a height at which hydrological changes and microclimate changes are more likely, but dependant on soil profiles, local climate, and slopes of cuts and fills).
- Where roads separate otherwise continuous intact native ecosystems, reducing 'core' habitat, including wetlands/lakes, and continuous edges (such as riparian areas and remnants on cliffs or terrace scarps). Note that where stormwater treatment wetlands are present, these should be on the same side of the road as natural wetlands to minimise wetland animals moving across the road.
- Where a coastal zone or tidal inlet or coast is traversed by a road.
- Where roads are part of a wider infrastructure corridor (eg, alongside powerlines, canals, above-ground telecommunications and/or rail; Figure 2.15).

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[59] https://www.nzta.govt.nz/assets/resources/supporting-road-lighting-research-work/2021-The-Road-Safety-and-Environmental-Impact-of-LED-Spectra-in-route-lighting.pdf

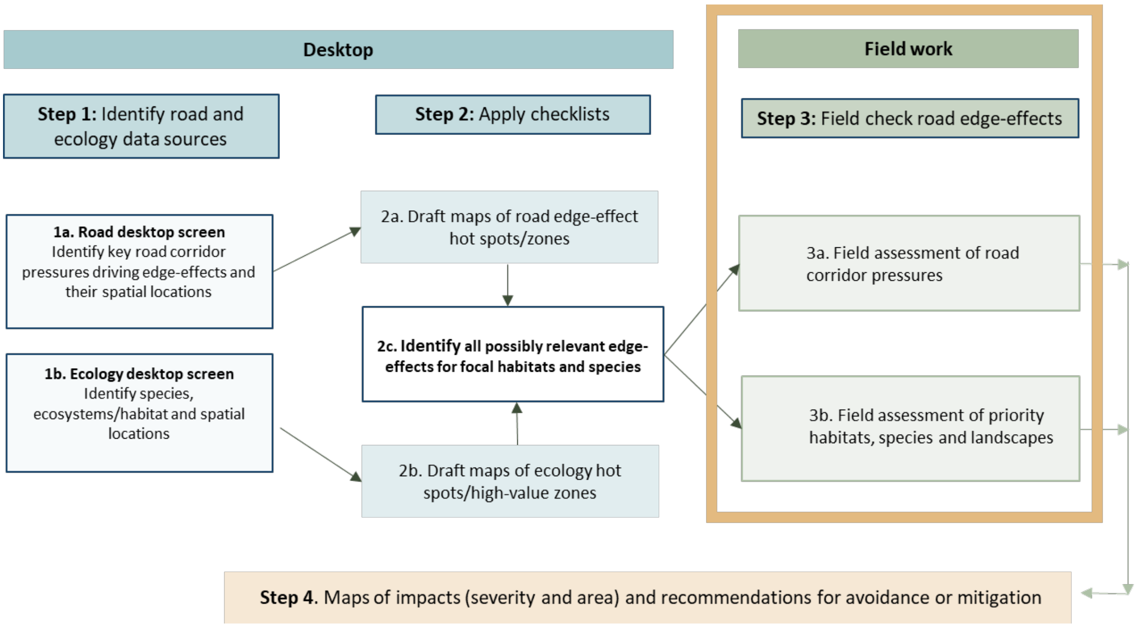
[60] 110 m is identified as a barrier for vulnerable forest birds such as New Zealand robins (Richard & Armstrong, 2010), but data are limited and do not include road traffic. Smith et al. (2017) provide recommendations for New Zealand long-tailed bats.

- Where roads facilitate movement of pest plants and/or animals to ecologically intact areas.

Figure 2.15 Co-location of linear infrastructure can concentrate impacts, generally leading to better ecological outcomes than separating them across landscapes, as shown here where riverbed and banks needed to be heavily modified to protect SH73 and rail bridges from flood damage. (Photo taken April 2021.)

2.1.3 Step 3: Field work

Figure 2.16 The road edge-effects assessment method, highlighting Step 3.



Step 3a: Field assessment of road corridor pressures

The objective of field assessment is to identify biodiversity threats and opportunities difficult to detect from the scale of the regional/national maps used in Step 2 (typically 0.5–1 ha) and to ground-truth the outcomes from Step 2 (Figure 2.16). Examples of threats include:

- pest plants within the corridor (especially ‘outliers’ and low-frequency plants) or on neighbouring land
- the degree of connectivity between road water tables and surface waters
- road edge maintenance treatments (especially herbicide use but also removal of plants that may grow into the clear zone, and tree seedlings that will be removed because they are non-frangible).

Examples of opportunities include:

- specific habitat features not related to dominant indigenous vegetation such as coarse wood, cut batters, and native understoreys in non-native tree canopy
- adjacent areas that are ungrazed/unmown because the road reserve and topography isolate them
- non-native trees that are potential important food for native fauna (eg, eucalyptus trees for nectar-feeding birds; willows for kererū) or habitat (eg, bat roosts, perching native plants).

Bridges and a selection of culverts should be specifically checked as key pressure points as these areas:

- often have steep slopes where pest plants can establish and spread downstream (with the distance being highly variable, depending on species and water-table characteristics; see examples in SH73 case study, section 4)
- are where stormwater runoff enters
- are where roadkill is often concentrated.

In both case studies, pressure points included areas where other linear infrastructure was co-located (Figure 2.17). The two case studies also revealed unique pressure points and pressures. In the SH73 case studies, pressures included the following features absent in SH16/18:

- isolated pest plants within the road corridor and largely absent from the adjacent landscape, such as hawthorn (Figure 2.17), apples and stone fruit (for weedy species this represents a critical opportunity lost to stop future adverse effects)
- extensive use of herbicide around marker posts and culverts (Figure 2.18)
- gravel stockpiles – these can be sources of weeds and may be used for informal public access leading to fires and rubbish-dumping (Figure 2.19)
- rest areas landscaped with pest trees (Figure 2.20).

Figure 2.17 An isolated individual (outlier) of the pest plant hawthorn in flower on SH73. (Photo taken April 2020.)

Figure 2.18 Use of herbicide to maintain a 'vegetation clear zone' around marker posts has created bare strips ~6–10 m long (the specification is minimum 3 m). These allow more aggressive species to establish that may have greater potential to invade adjacent natural habitats than the browntop grasses that otherwise cover the ground in mown areas. (Photo taken April 2021.)

Figure 2.19 A large area beside the railway used during construction of the new highway to store resources and excavated gravels creates a very wide but localised zone of impact that is partly naturally revegetating but vulnerable to invasion from weeds such as broom and Russell lupin. (Photo taken April 2021.)

Figure 2.20 This rest area west of Castle Hill Village contains weed trees – including silver birch (*Betula pendula*) and willow – that are largely absent from the adjacent landscape and potentially invasive. The rest area also provides access to the Porter River for fishing. (Photo taken April 2021.)

The SH16/18 Auckland case study identified a different range of road edge-effect pressures, which included:

- thin planted strips of native vegetation with high vulnerability to edge effects, including noise, light and pest plants, especially along on- and off-ramps, traffic islands and some noise walls – these were primarily established for landscaping, not as ecological resources
- high frequency of private land with shelter belts, gardens and 'waste' areas (including riparian zones) containing invasive tree species spreading onto native road corridor plantings
- areas of native planting with exposed soils that are vulnerable to pest plants spreading from adjacent areas – such areas are often steep slopes and sites with high plant stress (shallow rooting depths) and/or low planted species diversity, particularly flax and karamū
- headwaters and upper reaches of most streams that have been, or will be, piped as adjacent land is converted from farmland to urban land uses – this reduces the value of highway runoff and riparian mitigation as re-seeding of invertebrates downstream is greatly diminished.

Steb 3b: Field assessment of priority habitats, species and landscapes

This aspect of the field assessment focuses on verifying the ecosystem condition in areas where databases and maps generated from steps 1 and 2 indicate biodiversity values are high (ie, the most can be lost) and where biodiversity gains could be made. It also identifies cryptic areas that may be small or have a dominant canopy of non-native species. The assessment is largely a drive/walk past, so can usually be done under inspection protocols, with stops at predicted hot spots. Impacts are influenced by the status of the road, which may be divided into construction (short term), defect liability (medium term 5–10 years, before canopy closure occurs on earthworked and rehabilitated areas) and operations & maintenance (where long-term and cumulative edge effects on biodiversity are most important).

Examples of priority habitats and species identified in the SH73 case study are:

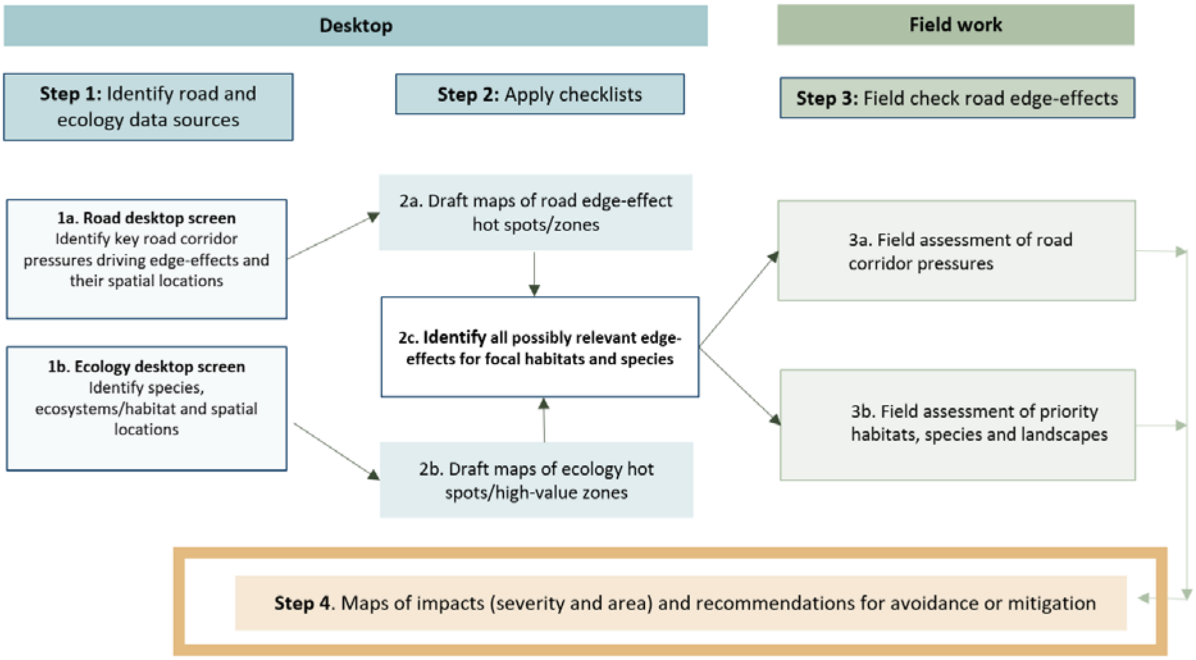
- mountain beech trees supporting yellow mistletoes (Figure 2.21)
- mitigation planting of threatened *Coprosma acerosa* that is receiving heavy browse pressure from hares where branches are within browse height
- remnant ungrazed areas that include riparian areas and wetlands within a grazed and ploughed landscape (Figure 2.22).

Figure 2.21 An isolated mountain beech tree (left photo) with many yellow mistletoes (right photo) at the eastern entrance to Arthur's Pass Village has been buffered by recent plantings that also reduce adverse impacts from vehicle access. Beech trees along road edges have higher numbers of mistletoes than those in 'core' areas, maybe due to higher light levels. (Photo taken April 2021.)

Figure 2.22 The inside of a curve on SH73 creates a large area crossing a shallow gully that is not grazed and includes a small wetland. This is an opportunity to create a biodiversity 'node' or steppingstone across a farmed valley floor where adjacent pasture has low biodiversity values. (Photo taken April 2021.)

2.1.4 Step 4: Finalise maps and recommendations for avoidance or mitigation

Figure 2.23 The road edge-effects assessment method, highlighting Step 4.



In the final step, field visit findings are used to finalise a map or maps that show the indigenous biodiversity areas near the road corridor, and key road edge-effects on biodiversity (Figure 2.23). These could be colour-coded red to green to represent estimated severity, reversibility, and importance/priority for actions. A variety of scales could be used to match the roadside/project. A list of 'hot spots' and recommendations for potential actions using the effects management hierarchy would also be prepared, and the hot spots would be identified on a map.

Examples of recommendations for actions to reduce and mitigate road edge-effects in the SH73 case study included the following.

- Identify and remove 'outlier' weeds to reduce their spread into adjacent landscapes with high conservation values (Figure 2.17).
- Change management of clear zones around marker posts and culverts to reduce bare areas and sprayed areas (Figure 2.18).
- Enhance biodiversity nodes within farmed landscapes (Figure 2.22).
- Replace pest plants in rest areas (Figure 2.20, Figure 2.26).
- Enhance barriers that protect vulnerable alpine habitats from weed invasion (Figure 2.25).
- Reduce spread of lighting around Arthur's Pass Village while retaining road safety (Figure 2.13).

This road edge-effects assessment would be followed in individual capital construction projects by detailed field work and consultation to confirm distributions of local species and populations, ecosystems and impacts (Figure 2.24). Such consultation is likely to draw on local and specialist knowledge – for example, local mana whenua (in particular regarding taonga species), regional and district council biodiversity staff, QEII representatives, and DOC. In some areas, research organisations such as universities and Manaaki Whenua may have research projects; in others, conservation groups such as Sanctuaries of New Zealand and/or other non-governmental organisations (NGOs) are likely to be active. A specific challenge of road management is ensuring health and safety of people working (or volunteering) in these potentially dangerous places. Safe access should be specifically designed into new capital projects.

Figure 2.24 The road edge-effects assessment method showing potential links to more detailed field investigations, maintenance contracts, performance monitoring and road design and landscaping guides.

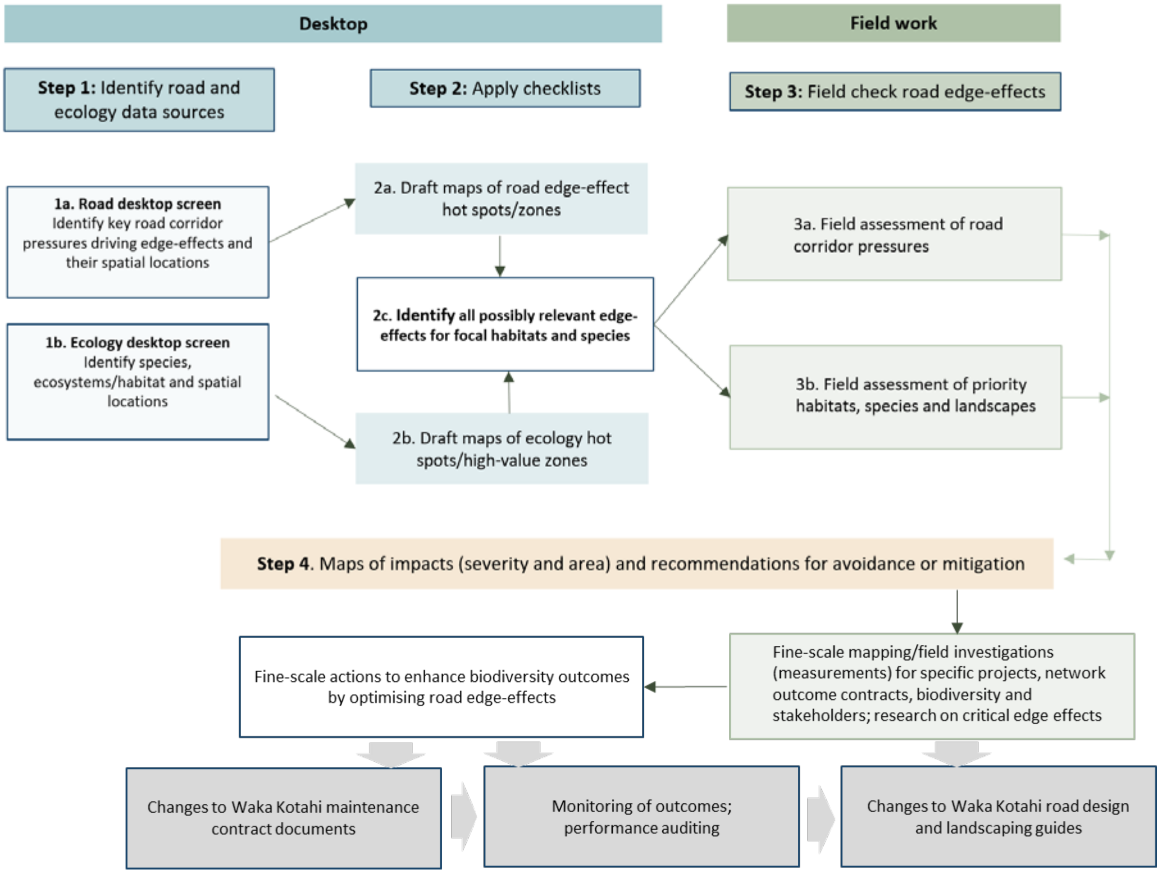


Figure 2.25 This densely vegetated edge in Arthur's Pass National Park is resistant to weed invasion. The vertical rock walls, which offer no sites for seedling germination, and the concrete kerb with no gravel margin have eliminated areas vulnerable to weed invasion. (Photo taken April 2021.)

Figure 2.26 Rest areas near Castle Hill Village. Upper photo: Car park recently renovated to remove a shelter belt of weed pine trees and replace with native species. Lower photo: In both sites, impacts of cars are reduced by defining edges (with boulders, wood and/or bollards). (Photos taken April 2021.)

3 Case study: SH16 and SH18, Auckland

3.1 Purpose

This case study tested the draft road edge-effect assessment method. Desktop-generated maps and associated checklists were then field-checked. The field check took about 5 hours and included most bridges, major culverts, and high-priority ecological areas. A series of photographs from five key sites along the case study highways are used to show a variety of road edge pressures and ecological values at each site. Following the case study, the method and outputs for assessing road edge-effects were simplified, as presented in section 2.

3.2 Case study overview

The modern Westgate to Hobsonville (SH18) and Westgate to Kumeu (SH16) highways carry high volumes of vehicles and have large impervious surfaces, so deliver high traffic-related noise, light, air (NO_x/SO_x) and stormwater impacts compared to most New Zealand roads. The Westgate to Hobsonville section of highway opened in 2011. This four-lane separated highway carries about 60,000 vehicles/day (AADT). A combination of planted buffers, bunds, and noise walls are used to mitigate traffic-related edge-effects on adjacent houses, which include new master-planned housing areas such as Hobsonville Point. However, noise walls are absent where future urban or residential development is not provided for. The Westgate to Kumeu section of highway carries about 30,000 vehicles/day (AADT). It includes both a new, separated highway with substantial planted buffers and stormwater wetlands, and an old section of unseparated, single-carriage road with very narrow verges.

SH18 crosses the upper reaches of the Waitematā Harbour at Hobsonville. This estuary has significant marine ecological values as it supports a range of shorebirds, including migratory species. Very long (> 50 m) culverts carry headwaters of small first- and second-order streams under the highway. The headwaters and upper reaches of most of these streams have been piped, or will be piped when adjacent land is converted from farmland to urban and industrial areas. Stormwater runoff from both SH16 and SH18 is slowed and treated in stormwater treatment wetlands and/or ponds. These were probably designed to Auckland Council 'TP10' standards that focus on reducing total suspended sediment by 75%; however, the high vegetation cover of most ponds is also likely to mitigate high temperature, which is an important contaminant of small streams (Young et al., 2013). The habitat value of ponds is enhanced by sediment forebays that allow regular maintenance with minimal disturbance to the main wetland.

Both motorways run through predominantly urban and peri-urban areas, supporting small agricultural, horticultural and life-style blocks with very little natural native vegetation (Figure 3.1, Figure 3.2). The entire highway corridor is on land with the highest threatened environment classification (terrestrial) of less than 10% of original native vegetation remaining (Figure 3.9). Any remaining native habitat on intact soils (ie, unploughed, not stripped) therefore has high potential ecological value despite most existing remnants being severely pressured by a range of smothering pest plants, of which acacia (wattles), tobacco weed, privets (large and small leafed), casuarina, pines, honeysuckle, pampas and bamboo are the most common. Remnant native vegetation is generally linear, being along coastal margins and watercourses. Although the Auckland Council Significant Ecological Area (SEA) map shows many of these small remnants (Figure 3.10), it excludes the majority of the transportation corridors that have been planted with native vegetation, other than some stormwater ponds. Given these areas are more extensive than the remnants, this may reflect the age of the mapping relative to the planted areas and/or low value placed on planted areas. Regardless, retention of remnants, removal of pest plants in and around the remnants, and their buffering with new native plantings (to improve their condition) are potential benefits from highway construction (Figure 3.3).

Figure 3.1 SH16/18 with 100-m and 500-m buffers from the centreline mapped over land cover (LCDB v5.0).

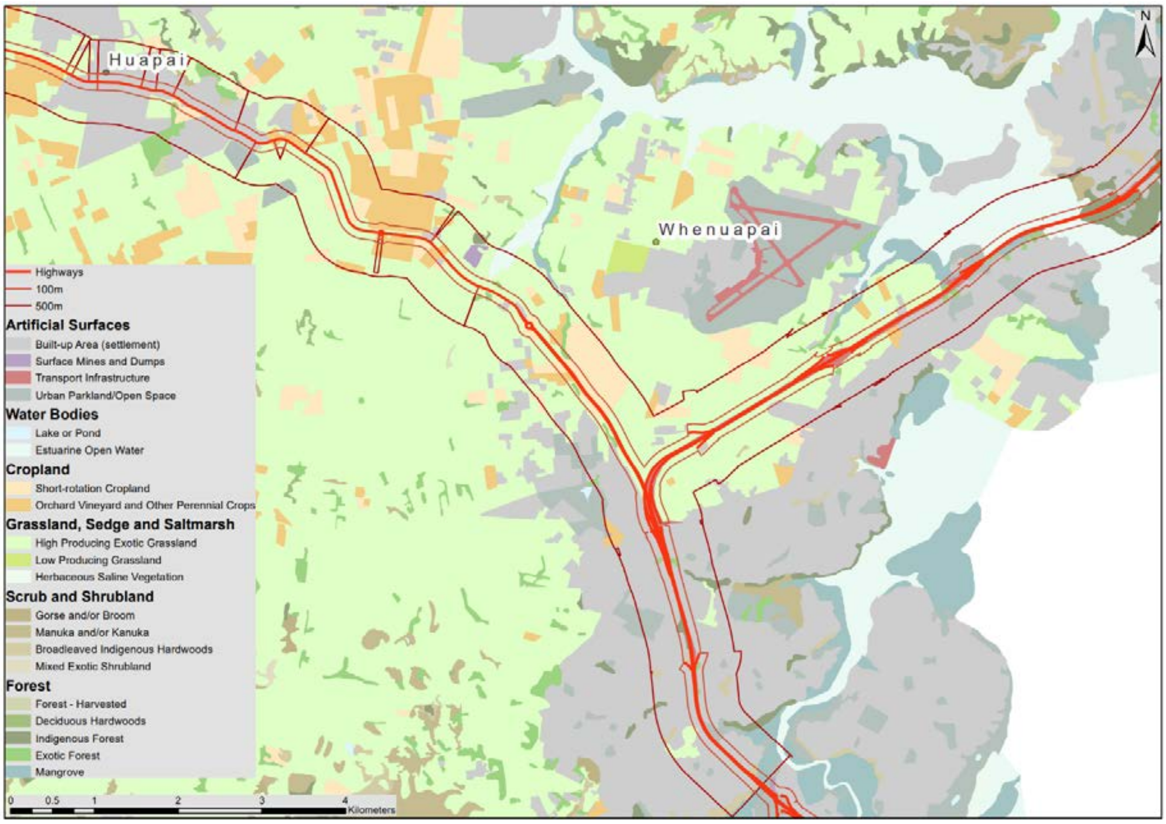


Figure 3.2 SH18 showing locations of traffic monitoring (darker red colours represent higher traffic numbers).

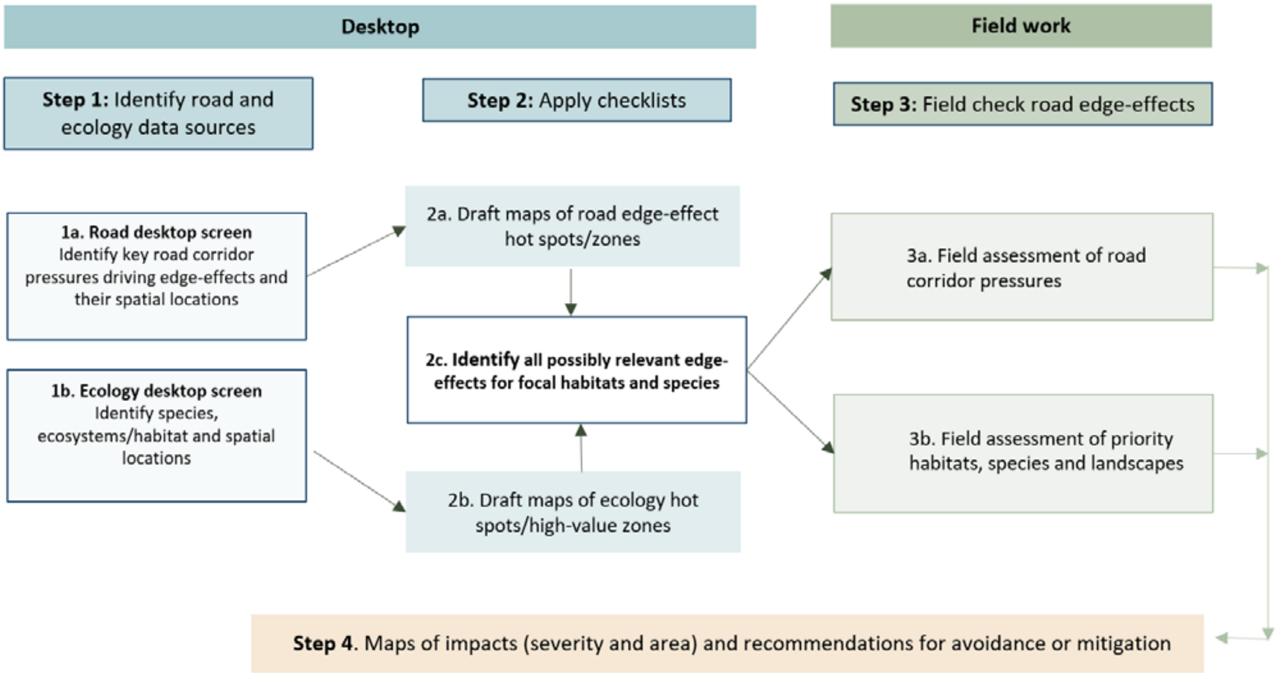
Figure 3.3 Hobsonville section of SH18 looking west from Trig Road interchange, showing orange noise wall, extensive lighting, and native planting into mulched, re-contoured and earthworked areas.[61] (Photo taken in 2011.)

3.2.1 Road edge-effects assessment overview

The road edge-effects assessment method has four-steps (Figure 3.4). The first two steps are desktop analyses designed to focus fieldwork on areas with potentially high impact and/or high ecological value. The third step is a rapid field verification that delivers information used in Step 4. Step 4 produces maps that identify locations of priority road edge-effects with site-specific pressures and recommends options for their avoidance or mitigation – that is, adopting the effects management hierarchy. These options are also informed by reviewing spreadsheets that summarise anticipated road edge pressures and highlights factors that generally exacerbate or mitigate specific edge-effects, as well as ecological sensitivities (from Step 2). This road edge-effect assessment process does not assess direct loss of habitat due to the road footprint, but it does include degradation and fragmentation of habitats and roadkill as edge-effects. The assessment also focuses on terrestrial effects; however, common aquatic impacts can be inferred from the assessment of stormwater runoff quality and quantity and assessment of watercourses where road culverts, bridges and discharges from wetlands provide access.

[61] Photo sourced from Wikipedia: https://en.wikipedia.org/wiki/State_Highway_18_(New_Zealand)#/media/File:Upper_Harbour_Motorway_at_Trig_Road_Interchange.jpg

Figure 3.4 Proposed steps in assessment of road edge-effects for land transport infrastructure.



3.2.2 Steps 1 & 2: Identify road and ecology data and apply checklists

Two desktop analyses screen for (a) key road pressures that drive the road edge-effects on ecological values and (b) the sensitivity of ecological values to road edge-effects, using the databases listed in Table 3.1 and Table 3.2 (a detailed explanation is given in section 2). In addition, a new database available in the Auckland region is ‘Ruru’. This is Auckland Council’s new conservation information system funded by the Natural Environment Targeted Rate. It is a connected set of digital tools for conservation operations and provides consistent and more efficient methods for data collections, storage, visualisation, analysis, and reporting. More importantly, it allows visibility across Auckland Council and all the efforts in protecting and restoring the natural environment. It complements the Auckland Council conservation website[62] launched in 2020 to provide information on biodiversity, conservation groups, projects, and actions in Tamaki Makaurau.

The outcomes of Steps 1 and 2 for this case study are described below. The most significant road corridor pressures are probably noise and light, and the most sensitive ecological areas are coastal estuary, wetlands, coastal forest/shrubland remnants and riparian areas.

[62] https://www.tiakitamakimakaurau.nz/

Table 3.1 GIS layers used to form a draft road edge-effects 'pressure' and 'hot spots' map for field verification.

Map/Layer	Description and rationale
Waka Kotahi road data	• Road centreline* (RAMM_CL#) • Bridges* (detail in Bridge data system) – most bridges are easily identified in the field as they are individually sign-posted • Culverts[63] from 'Drainage database', selecting attribute 'drain type' 'culverts'# • Street lighting – point data on streetlight assets# • Noise wall# – metadata include wall construction material, height and offset[64]
Traffic counts	AADT* and % heavy vehicle*
Waka Kotahi effects data	Noise contours – dB levels in $L_{Aeq(24)}$# [65]
Waka Kotahi effects data	NO_x and SO_x emissions map* [66]
Waka Kotahi property	Property owned by Waka Kotahi#

* indicates data are publicly available through LINZ or Waka Kotahi public website
# indicates data layers provided by Waka Kotahi for this project

Table 3.2 Maps and data used to inform a draft map of biodiversity values for field verification. All but SNA layers are publicly accessible.

Map/Data source	Rationale for use
Land Cover Database (LCDB) v5.1	Maps the dominant vegetation cover. The specific 'Wetlands' layer was used to locate these ecosystems.
Protected Area Network – New Zealand (PAN-NZ)	This identifies land parcels probably managed primarily for biodiversity outcomes. It includes most land managed by DOC and QEII covenants, and regional council parks.
Significant Natural Areas (SNAs), Auckland Council	Auckland Council has publicly available maps of SNAs,[67] which use a modified Singers and Rogers (2014) classification system; these often overlay parts of council parks, which were also mapped.
Threatened Environment Classification (TEC)	This uses dominant indigenous plant cover from LCDB v4.1 as a surrogate for biodiversity and identifies areas that are most threatened due to a combination of small residual area and legal protection.[68]
Biodiversity Atlas	Point records of biodiversity, useful to scan for rare and threatened species and includes 'research grade' observations from iNaturalist.
iNaturalist NZ	Point records. The most useful data are 'research grade' observations of fungi, invertebrates, and groundcovers that are not recorded in other databases (other than the Biodiversity Atlas); also useful for native plants in areas with non-native plant canopy, local flowering and fruiting times, and pest plants.
New Zealand Plant Conservation Network (NZPCN)[69]	Comprehensive plant lists for many areas along the highway covering native and non-native species.

[63] 'Drain Type' includes 30 different attributes, of which 'culverts' are the most numerous (45,691 are recorded). Stormwater treatment devices that may provide habitat values (wetlands and stormwater ponds) are not captured in the RAMM database. Fish passage is recorded at only five sites nationally, but this is expected to increase rapidly.

[64] Vehicle safety barriers made from concrete could be useful to include where they act as barriers to wildlife, but these are best to assess in the field, so are not included.

[65] $L_{Aeq(24h)}$ is time-averaged A-weighted sound pressure level over 24 hours, in decibels, the unit of sound.

[66] https://www.nzta.govt.nz/roads-and-rail/highways-information-portal/tools/air-quality-map/

[67] https://www.tiakitamakimakaurau.nz/conservation-map/

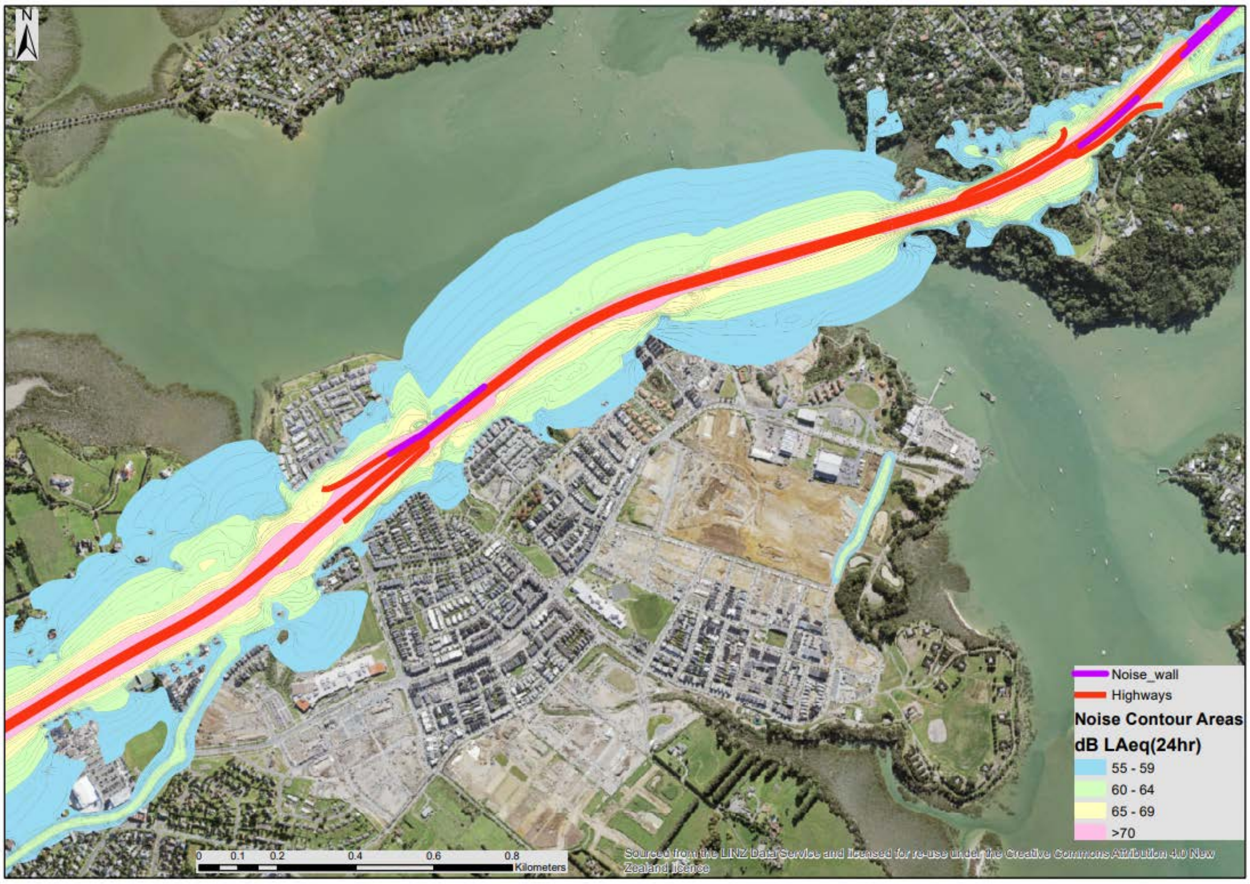
[68] Areas with less than 10% and 20% of original ecosystems are priority candidates for avoidance and added suitable buffering to expand the 'core' and protect from damage and weed invasion.

[69] https://www.nzpcn.org.nz/

3.2.2.1 Noise

Noise is the road edge-effect with potentially the broadest and most intense ecological impact, given stormwater impacts are moderated by treatment devices. Modelled noise contours (Figure 3.5, and for the wider areas in summary, Figure 3.27 to Figure 3.29) show noise between 55 and 59 dB averaged over 24 hours (ie, over day and night) extends 200–300 m from the centreline. This zone is widest, reaching 300–400 m from the centreline over the ecologically sensitive estuaries and coastal cliffs where the highway is elevated and there is minimal attenuation (ie, water or non-vegetated estuary) (Figure 3.5). Noise levels reflect high vehicle numbers and speeds of 80–100 km/hr. Noise contours for the old, single-lane highways near Huapai are less than half that of the new highway. Noise contours do not show peaks at acceleration/deceleration zones of highway on- and off-ramps or associated roundabouts, perhaps because most of these areas are single lane and traffic speeds are slower. The spread of noise is reduced where the roads are within cuts and behind noise walls or bunds (Figure 3.5). Background noise from adjacent urban areas such as supermarkets and light-industrial areas could moderate, or exacerbate, impacts of road-generated noise on ecology depending on the species and distribution of noise over seasons and days (night/dark). No New Zealand data are available to assess impacts of traffic noise on birds or invertebrates; however, overseas research indicates that sensitive bird species in the estuary area such as estuarine waders and migratory birds are likely to be adversely affected, and the habitat degraded, particularly in combination with impacts of artificial light.

Figure 3.5 SH18 near Hobsonville, showing noise walls (purple lines) and modelled noise contours; the lowest mapped noise level zone (in blue) is 55–59 dB $L_{Aeq(24)}$.



3.2.2.2 Light

The impacts of streetlights associated with the state highway are likely to impact some native animals due to the lighting intensity and spread into adjacent SNAs (estuaries, remnant shrubland/forest), planted native vegetation and constructed wetlands. The majority of both highways are lit with tall twin-lamp towers located in the median strip between the lanes and single lights along on-ramps; most bridges are also lit (Figure 3.6). These light towers are generally visible from outside the motorway buffer, being shielded by landscape or trees in only a few locations. No data were available on the extent to which any lights are shielded or otherwise managed to reduce impacts. Animals in the coastal zone, wetlands and streams are particularly vulnerable to artificial light (Zapata et al., 2019), although in some places effects may be moderated by ‘background light’ from adjacent land in urban and retail areas. The additional impacts of vehicle headlights are limited along most road sections due to relatively straight roads, bunds, noise walls and/or vegetated buffers that limit penetration of headlights into adjacent areas. Headlight penetration at roundabouts is generally limited by roundabouts being sunk low in landscapes and by buffer planting, but could be important where roundabouts are adjacent to stormwater wetlands. No data were available on the presence of nocturnal native animals (eg, ruru, moths).

Figure 3.6 Location of streetlights and Waka Kotahi-administered Crown land in the SH16/18 case study area. Additional lighting was recorded in the field survey.

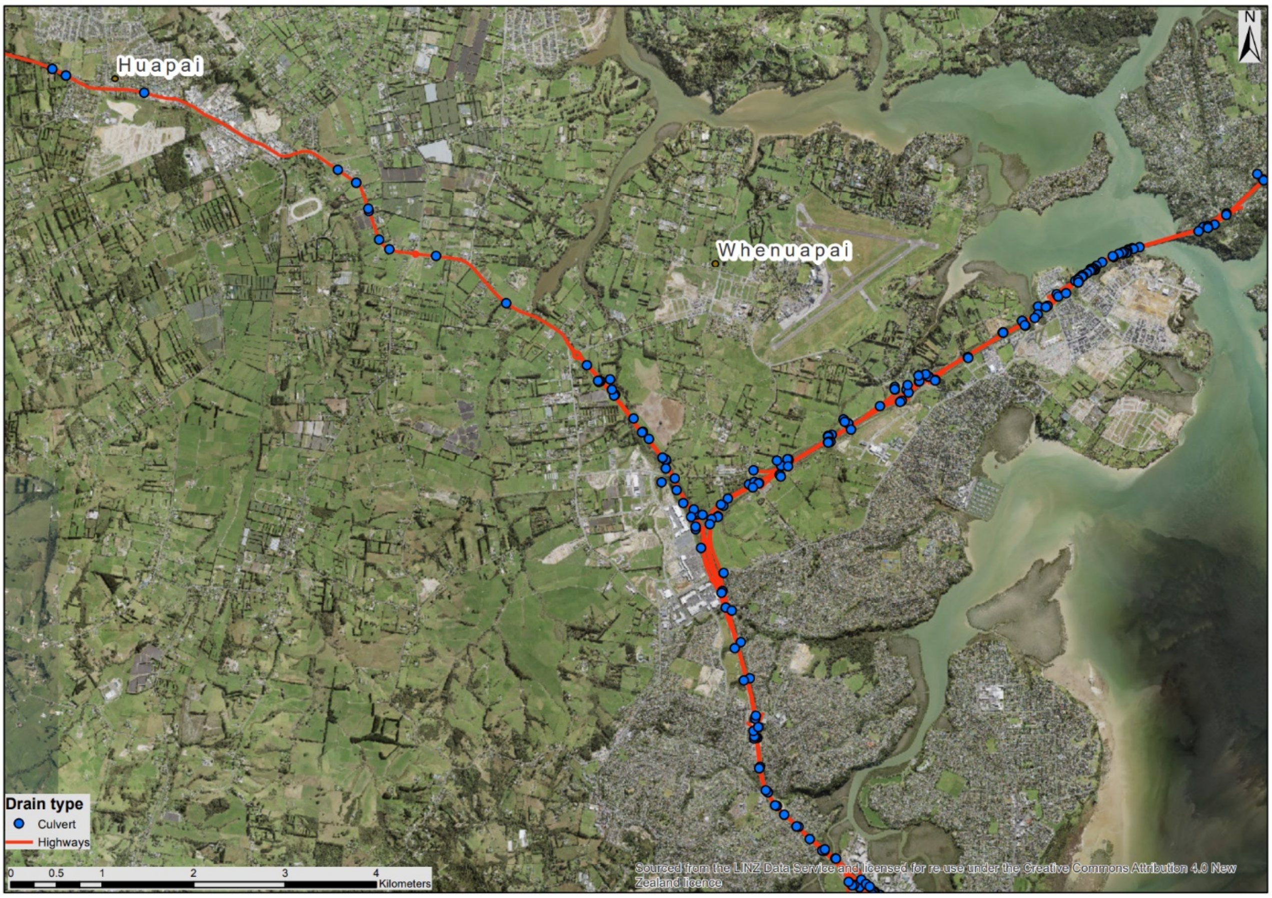
3.2.2.3 Stormwater runoff and hydrology

Stormwater runoff from both highways is expected to have high contaminant loads. The roads exceed vehicle numbers identified as the threshold for ‘high contaminant generating surfaces’ in the Auckland

Unitary Plan (Auckland Council, 2013[70]). The extensive impervious surfaces created by twin-carriageways with wide impervious shoulders that extend across the central median in places generates large runoff volumes and high peak flows. Many stormwater culverts carry water away from the road surface (Figure 3.7). Contaminants are also generated from herbicides used to control plant growth along road edges, road barriers, below signs and around drainage features. However, the area treated with herbicide does not include marker posts as these are absent along twin-laned sections. The ecological effects of stormwater contaminants are mitigated through treatment by using swales, wetlands and stormwater ponds. A climate characterised by many small rainfall events ensures a very high proportion of runoff is treated in these devices before it flows to watercourses and the Waitematā estuary. The stormwater ponds are also habitat for some plant and animal species, potentially exposing them to accumulated contaminants.

Extensive cuts, fills and construction of earth bunds have changed soils and hydrology in the construction footprint. Original soils were a complex pattern of free-draining Allophanic Soils developed from harbour-deposited pumice flows and imperfectly and poorly drained Ultic Soils. Wetlands had been drained, but pockets of Organic Soils (peat) remained where they were present. In contrast, the earthworked soils replaced over pervious areas of the large highway construction footprint are uniformly imperfectly drained and a relatively uniform 20–30 cm depth of mixed, fine-textured topsoils over heavily compacted, impervious subsoils, which reduce potential connections between surface water and groundwater. Where slopes are gentle, these new soils are generally poorly drained and develop perched water tables in winter.

Figure 3.7 Culvert locations (blue dots) along SH16/18 with satellite photograph underlay.

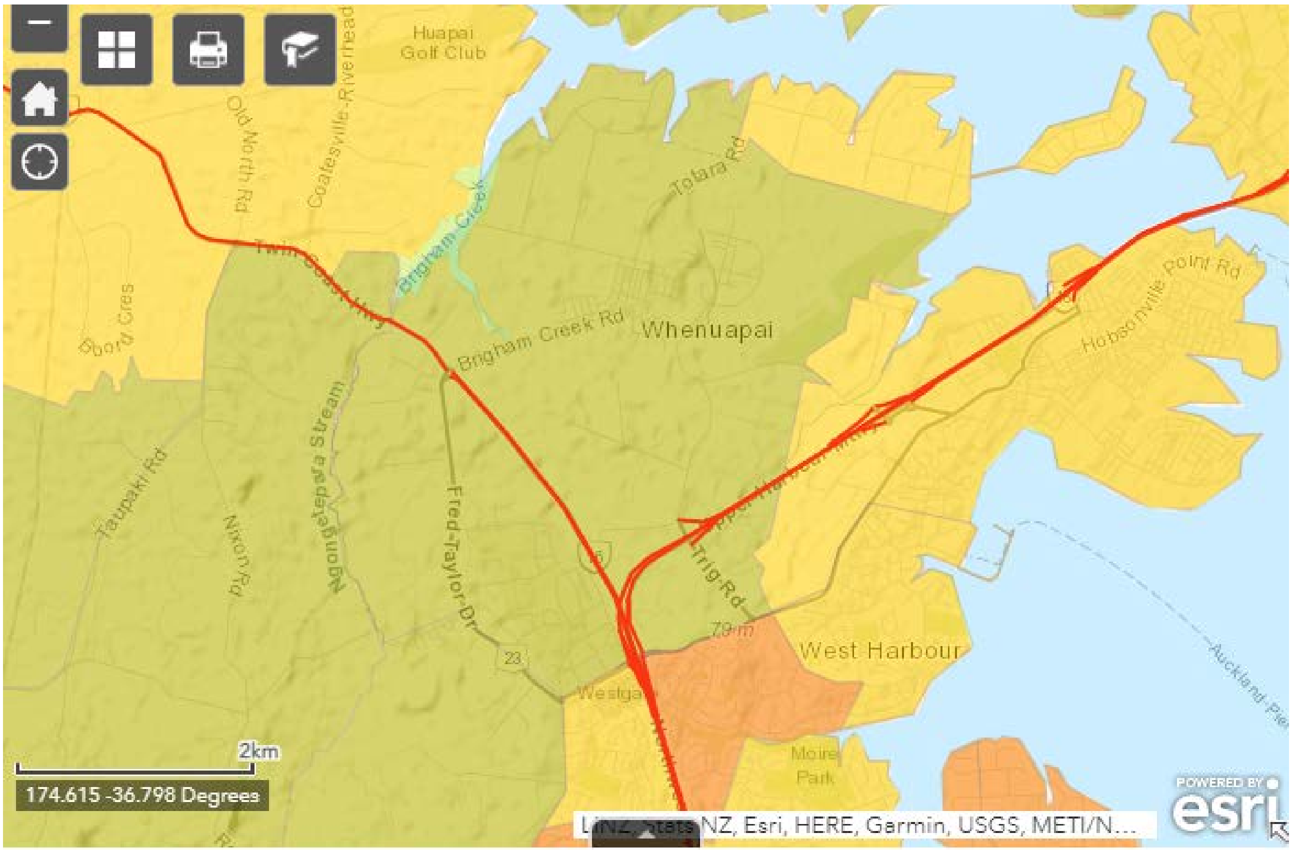


[70] https://unitaryplan.aucklandcouncil.govt.nz/pages/plan/Book.aspx?exhibit=AucklandUnitaryPlan_Print

3.2.2.4 Air emissions, heat and wind

The effects of the highway traffic on NO_x and SO_x emissions are modelled as being minor at the scale mapped, as air quality is driven by adjacent urban/industrial land uses, the flat to gently rolling landscape and the proximity to coastal winds (Figure 3.8).

Figure 3.8 Air quality as average PM_{10} (24 hr) for the SH16/18 case study area (orange = 40–50 µg/m^3; yellow = 30–40 µg/m^3; green = 20–30 µg/m^3). These data are publicly available on the Waka Kotahi website.[71]



3.2.2.5 Habitat modification and fragmentation

SH16 and SH18 cross a lowland landscape where less than 10% of the original indigenous vegetation remains (Figure 3.9); the entire highway corridor therefore has the highest threatened environment classification (terrestrial). All remaining natural habitats therefore have high value, despite being very small and often degraded by weeds with high edge-effects. Auckland Council maps show that SEAs near the state highway include coastal remnants along both sides of the SH18 Hobsonville peninsula and a riparian remnant near the northern end of SH16 (Figure 3.10). Both these sites are targets for field investigations. Auckland Council maps of 'ecosystems – open water' include some constructed stormwater ponds, including some state highway ponds/wetlands. None of the extensive, native-dominated vegetation planted as highway buffers is included in SEAs. A priority of the field assessment (Step 3) was to assess the potential values of these areas, as maps indicated in most cases both new plantings and SEAs are exposed to 55–59 dB $L_{Aeq(24)}$ traffic-generated noise (Figure 3.5) as well as highway ALAN. The condition of the 'ecosystems – open water' was also identified, as the constructed stormwater ponds and wetlands may develop a dense rush and/or raupō cover, which is reduced when ponds are desilted.

[71] https://www.nzta.govt.nz/roads-and-rail/highways-information-portal/tools/air-quality-map/

Biodiversity Atlas, iNaturalist and NZPCN records for the area were sparse (Figure 3.11). This reflects the relative youth of adjacent public paths and walkways (more accessible parks and cycle ways are planned), and lack of public access to the highways themselves as fencing excludes dogs and people. iNaturalist included records of some garden escapes such as *Fatsia japonica*, alerting the field survey where to look for garden escapes. Three iNaturalist records were of threatened native species; however, all are unlikely to indicate populations on the motorway corridor: a bar-tailed godwit sighting was located on a shell bank where no banks are currently present; a forest gecko found on an adjacent road is more likely to have fallen from vegetation being transported than be a remnant population, and a Hochstetter's frog record in an exposed area with little cover was improbable.

Figure 3.9 TEC map of the SH16/18 case study area. The red shading represents areas that have less than 10% remnant native ecosystems.

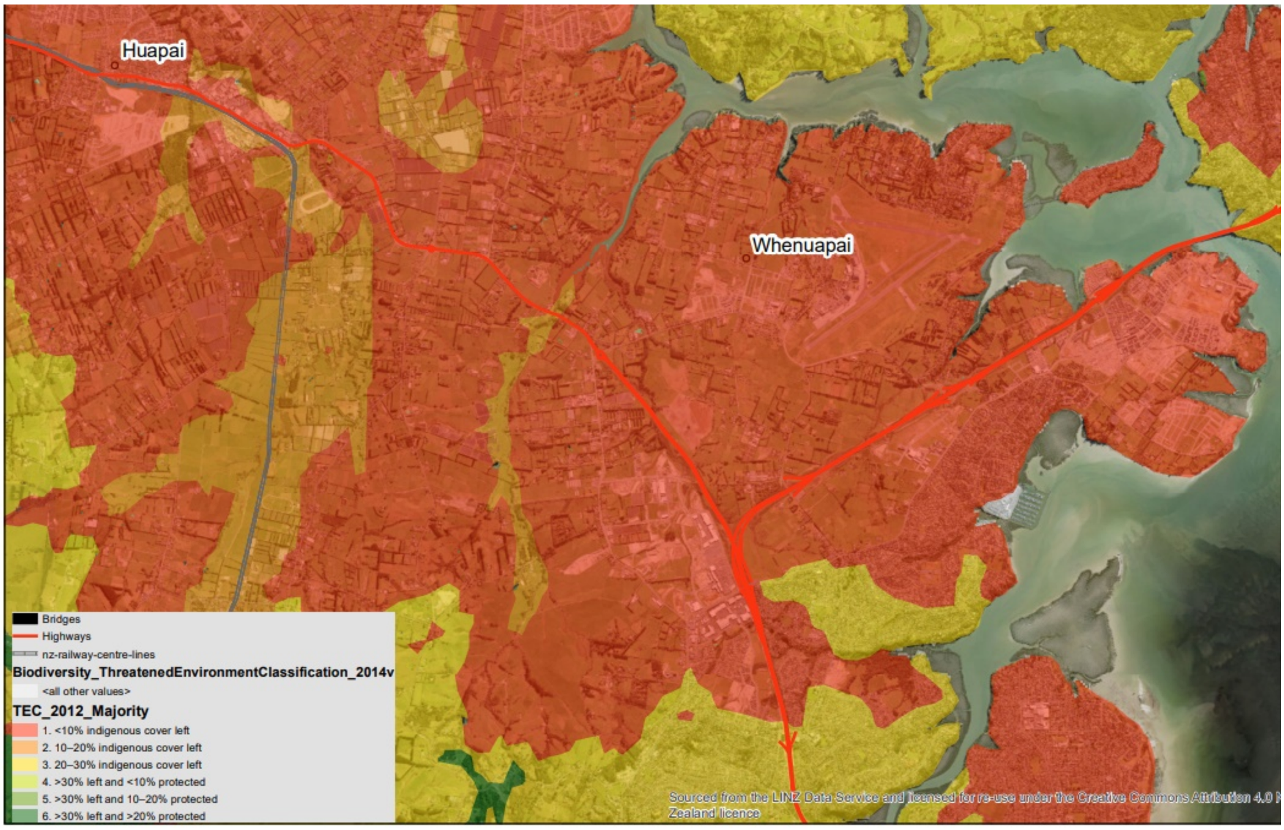
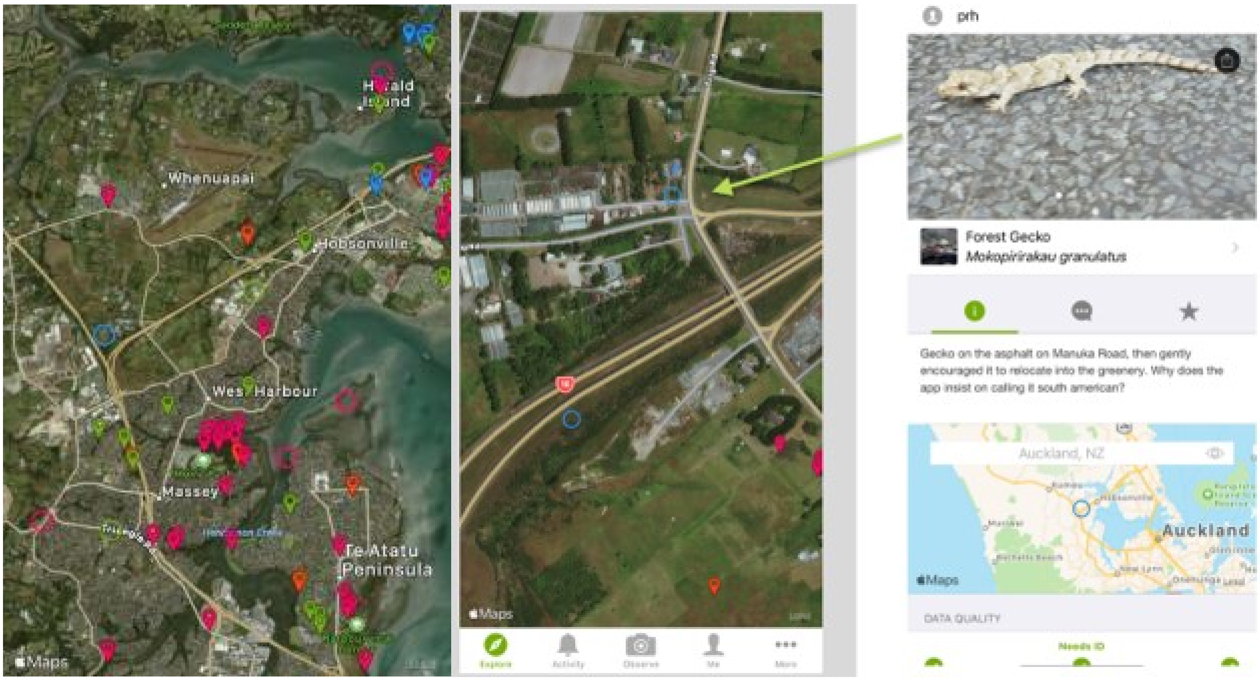


Figure 3.10 Conservation maps showing Auckland Council delineated SEAs (dark green) and Auckland Council parks (light green) with waterways (blue) and open water/wetlands (purple) that include some constructed stormwater ponds.[72] For scale, in the top map, the main runway at Whenuapai airport (identified with a blue arrow) is 2,031 m long.

[72] These maps are publicly available at https://www.tiakitamakimakaurau.nz/conservation-map/. Auckland Council notes that the current extent (of classified ecosystems) layer, which uses a modified Singers and Rogers (2014) classification, is primarily used to guide Auckland Council's biodiversity/biosecurity work but is not complete and has some errors at the scale of mapping.

Figure 3.11 iNaturalist records for the SH16/18 case study area showing general absence of records, and an unexpected 'forest gecko' that probably fell from a truck carting its habitat of mānuka/kānuka or tree fern trunks.



The NZPCN website has plant lists for areas near the two highways,[73] including Herald Island by J Diprose (1997), the Greenhithe-Marae Road by C McKain (2001), and Waipareira Bay, Te Atatū, by M Cuttgin and EK Cameron (1994). These identify invasive plants that threaten remnants such as climbing asparagus, boneseed, willow-leafed hakea, prickly hakea, ivy, pampas, kahili ginger, wattles, fatsia, woolly nightshade and Chinese privet, but also native species adapted to roadside clay banks such as *Pomaderris amoena* (tauhinu) and *P. kumeraho* (golden tainui). These *Pomaderris* species can be managed during road construction and maintenance to promote natural revegetation of cut faces by:

- retaining 'uphill' remnant 'source' plants, allowing adequate distance from the vegetation clear zone to allow plants to reach a minimum 300 mm height (tauhinu) to 1 m height (golden tainui)
- ensuring surfaces are relatively rough (providing microsites for germination)
- not hydroseeding, fertilising, or placing topsoil on such cut slopes (to reduce competition).

3.2.3 Steps 3 & 4: Field work and recommendations

Findings of the field assessment are shown using five feature areas that demonstrate how the road pressures and ecology features are combined to identify 'hot spots of impact and opportunity' for the SH16/18 highway case study (Figure 3.12). The five feature areas are:

A. SH18 Hobsonville Waitematā estuary

B. SH18 Brigham Creek Road interchange

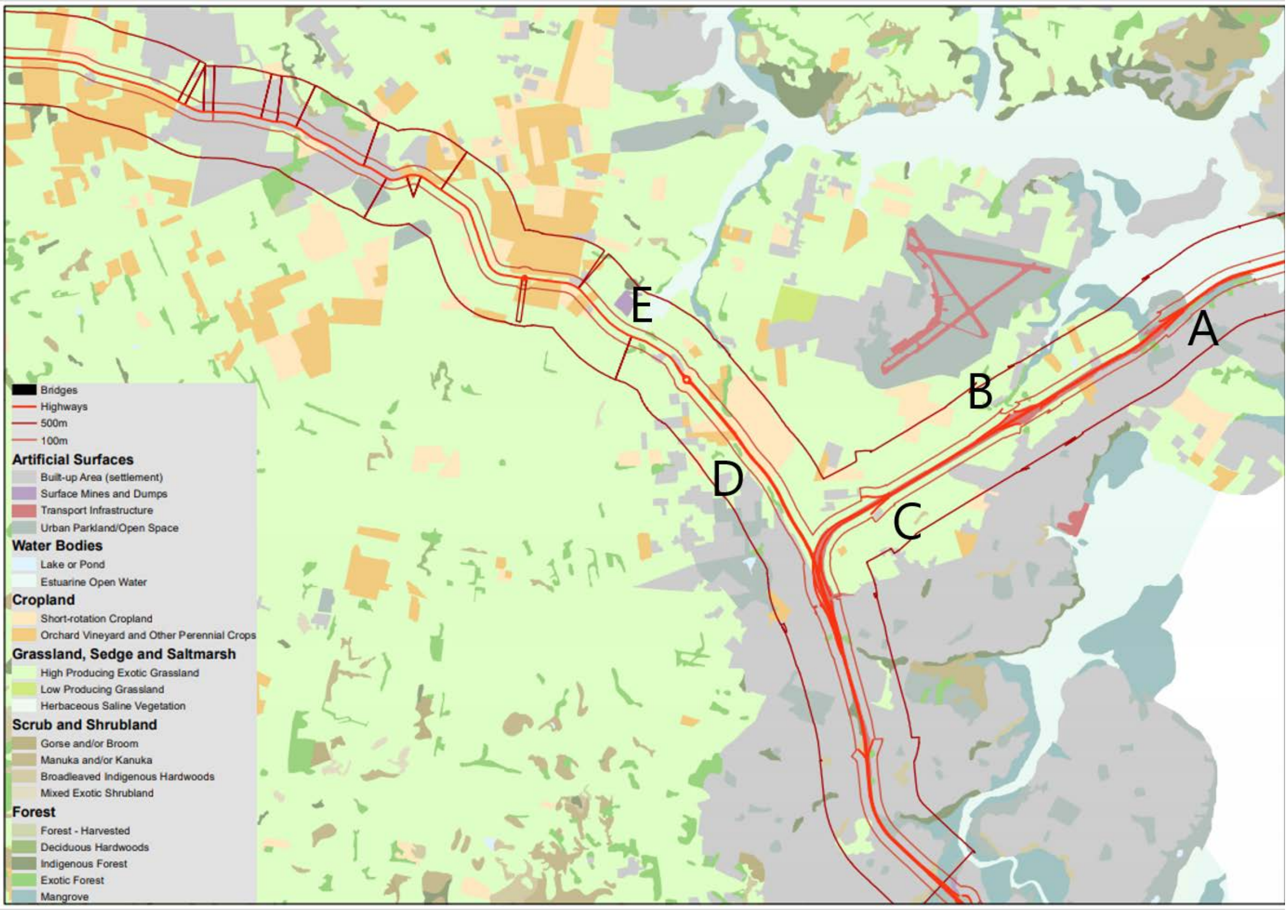
C. SH18 southern side of Trig Road

D. SH16 Westgate

E. SH16 Brigham Creek interchange.

[73] https://www.nzpcn.org.nz/publications/plant-lists/plant-lists-by-region/auckland/

Figure 3.12 Locations of the five case study feature areas on the LCDB v5.0 vegetation map.



3.2.3.1 Feature Site A: Hobsonville Waitematā estuary (Figures 3.13 to 3.15)

Observed features:

- SEAs identified by Auckland Council (coastal cliffs, wetland, and estuary) that include part of public parks with variable levels of disturbance.
- Extensive young (~10-year-old) planted native shrubland along motorway that ranges up to ~30 m width. Buffers vary in composition with some including a range of native woody ‘colonising’ species, including kānuka, mānuka, five-finger, karamū, māhoe, ngaio, karo, and māpou, with longer-lived trees such as karaka, tōtara and pōhutukawa. This has highest ecological value where it buffers and connects adjacent reserves and stormwater treatment areas in the adjacent Hobsonville subdivision.
- Plantings along on- and off-ramps form very narrow strips and are particularly close to live traffic lanes – these could negatively impact native fauna that feed on the margins by increasing the risk of road mortality. Kererū may be most vulnerable fauna due to their large body size and low manoeuvrability.
- Long-term native plant dominance and development of complex canopy structures is likely in many plantings as they include a variety of long-lived tree species that will both ‘emerge’ and ‘fill in’ spaces vacated by shorter-lived species such as karamū and koromiko. However, at this site, native dominance is not assured, as pest plant pressures from outside the highway corridor are moderate to high. Adjacent land contains shade-tolerant weed tree species (privet), and planted areas have individual pest plants (tobacco weed, acacia) that already over-top some native plantings. The potential for pest plant invasion is highest along narrow strips and/or steep slopes where plant stress is highest.

- The ecological values of habitat are probably reduced by high pressures from noise and light. Most planting is not protected by noise walls or bunds and is exposed to tall motorway lighting.
- People are excluded from most state highway areas. There may be higher pressure from predator animals that are not excluded, such as cats, given adjacent dense housing and higher pressure from pest mammals, given the difficulty of access for pest control. However, some pest control was obvious in the council reserves along the coastal cliffs. Krull et al. (2014) measured high densities of rats (27–52/ha) and found the highway was a barrier for rats, which did not cross the highway, although some hedgehogs crossed.

Figure 3.13 Site A. The SEAs in the foreground are adjacent to high road pressures of noise and light that are largely unbuffered. (Photo taken May 2021.)

Figure 3.14 Map showing the SEAs (dark green) that include those shown in Figure 3.13. Light green indicates Auckland Council parks. The red box identifies the areas checked in the field that were accessed from public walkways.

Figure 3.15 Site A. Top: Planted buffers and SEAs adjacent to stormwater ponds. Middle: View from over-bridge with extensive planting and pest plants in foreground (pampas and tobacco weed; photo taken May 2021). Bottom: This diverse but narrow planted strip provides visual amenity but probably minimal ecological values (photo taken May 2021).

3.2.3.2 Feature Site B: SH18 Brigham Creek Road interchange (Figures 3.16 to 3.18)

Observed features:

- Extensive ~10-year-old planted native shrubland along motorway. This planting has the most ecological value where large, wide areas buffer and connect with adjacent riparian areas and stormwater treatment areas. It has the least ecological value where thin strips screen noise walls (to control graffiti).
- Noise impacts on two potential 'ecology nodes' are moderated by noise walls and bunds. The potential of these nodes could be enhanced by replacing mown grass with more native trees and including adjacent Waka Kotahi-administered Crown land that includes a watercourse adjoining an SEA.
- Native plantings are being invaded by species from adjacent shelter belts and waste land: *Casuarina* (she-oak), acacia, tobacco weed, privets, ginger and honeysuckle. Narrow planted strips with low density of long-lived native trees and high proportion of flax and mānuka are vulnerable to invasion by pest plants; some of these areas now have low native plant cover.
- Exclusion of people and dogs by fencing from most areas probably enhances values of areas for some bird species by reducing disturbance: pūkeko, paradise ducks and shags were observed. A shag roosted in a retained tall tree near an old, constructed 'in stream' pond that was included in motorway planting (just left and downstream of the site shown in Figure 3.16).
- In-stream aquatic habitat values are likely compromised by removal (piping) of headwaters in recent adjacent retail and light industrial developments. However, most runoff from these sites and the highway is attenuated by stormwater treatment devices, and some adjacent riparian areas have been retired and planted with woody species that provide shade.

This is a useful site to contrast ecological values of different planting shapes and areas, different locations with respect to noise barriers, and integration (or not) with stormwater wetlands and riparian vegetation in the adjacent landscape (mirroring Site A). Ecological value can be maximised by planting large blocks where impacts of noise and light are moderated (eg, by noise barriers or bunds), and that abut existing remnants. Such ecological plantings should take into account weed pressures along their predicted succession and include long-lived trees.

Figure 3.16 Site B. Motorway buffer planting adjacent to riparian area. Retained golden tōtara and pest palms are shown in the background, and retained remnant is shown in the right foreground. (Photo taken May 2021.)

Figure 3.17 Aerial photo of Site B contrasts ecological value of planted areas. Narrow buffers with low ecological values and the larger, planted areas behind noise walls have higher values. Ecological value would be enhanced by linking plantings with the SEA in the riparian area at top left of the photo.

Figure 3.18 Site B. Ecological values of this stormwater wetland planted in sedges and rushes are enhanced by high plant cover, its location behind a noise wall, and the addition of adjacent terrestrial native shrubland planting that includes native trees. (Photo taken May 2021.)

3.2.3.3 Feature Site C: SH18 southern side of Trig Road (Figure 3.19)

This site replicates features seen in Site B. Ecological values are reduced by realigned and piped headwaters, high weed pressures in adjacent land, and urban expansion on adjacent land. Ecological values are enhanced for plantings behind noise walls and a vegetated stormwater pond and riparian area that are on the same side of the highway, which may help reduce potential for roadkill of wetland birds that inhabit these features.

Figure 3.19 Site C. Top: Large planted areas on cut embankments (circled) are exposed to high noise and light from the highway. Middle: Stormwater wetland that receives runoff from the adjacent motorway has dense raupō cover and adjacent slopes of flax and cabbage trees that are being invaded by pampas and grasses (photo taken May 2021). Bottom: A riparian area behind a noise wall dominated by gorse and non-native grasses, including pampas (photo taken May 2021).

3.2.3.4 Feature Site D: Westgate (Figures 3.20 to 3.22)

Observed features:

- In agricultural landscapes with low remnant native cover and narrow or absent riparian buffers, highway planting can enhance ecological values, especially where tall, non-weedy trees are retained to shade waterways, screen light from the highway, and maintain diverse structure and habitat (ie, cavities in wood, dead wood, complex bark and other features of large trees).
- Additional linear infrastructure of high-voltage transmission lines adds ecological pressures by requiring significant foundations, substations and long-term vehicle access, which reduces planted area, increases edges (reduces 'core') and restricts tree height. A sewage pump station is also adjacent to the buffer and stream, leading to adverse ecological effects if overflows occur.
- The potential to enhance ecological values is increased when adjacent land uses also support ecological values and increase the effective size and variety of native permanent ecosystems. Here, a new park and planted stormwater infrastructure add to highway planting and stormwater treatment wetlands. All the wetlands are on the same side of the motorway, which should help reduce roadkill of birds that move between wetlands.
- Planted buffers on cut faces of the adjacent (eastern) side of the highway border economic-sized fields within farmland and are therefore very narrow to minimise removal of agricultural land.
- Ecological values are enhanced where natural stream beds are not altered.
- The impact of earthworks required to create stable landforms can be severe. In parts of the adjacent park, earthworks have reduced root zone depth and/or drainage to the extent that growth of native trees requiring adequate drainage is impeded, making trees highly vulnerable to drought and waterlogging.
- As with other sites, ecological benefits are moderated by pressures of traffic noise, lighting and ongoing weed invasion from adjacent land.

Figure 3.20 Site D, looking towards Westgate, with a natural stream and mature trees buffered by new native plantings. The grassed area in the mid-right probably represents a missed opportunity, as planting this in native woody species would likely contribute more ecological value than planting the adjacent cut batter slopes. (Photo taken May 2021.)

Figure 3.21 Site D. Top: Aerial photo showing broad planted areas and three stormwater ponds adjacent to the natural stream channel. The pump station is top left, and the transmission facility is centre-right (both circled). Bottom: Power lines crossing the retained stream and motorway; gorse, pampas and acacia are in the foreground (photo taken May 2021).

Figure 3.22 Site D. Top: View across stormwater wetland and buffer planting to motorway with planted cut batter. Bottom: Construction of engineered landforms in an adjacent urban development. The photo shows how subsoils that limit root penetration are created. Drought stress and height of trees that can establish and mature are then determined by depth of topsoil, surface microtopography, and use of suitable mulches. (Photos taken May 2021.)

3.2.3.5 Feature Site E: SH16 Brigham Creek interchange (Figures 3.23 and 3.24)

Observed features:

- The observed features are similar to Westgate. Before the highway construction a very low proportion of native habitat and tree canopy was present, being restricted to shelter belts and ponds. The old highway that joins the roundabout typically has road verges that deliver negligible ecological values due to extreme narrowness, a high degree of disturbance, and proximity to traffic. These verges are sometimes managed by owners of adjacent land, and many verges are reservoirs of weeds. Farm ponds were generally constructed within the bed of streams, which potentially create barriers for fish and cause poor water quality where unshaded.
- New plantings, including the stormwater pond adjacent to the stream, have potential moderate ecological values that are enhanced by retention of tall, non-weedy trees (eucalyptus) that help shade the pond. This is the only site where logs are seen – these logs provide habitat for some invertebrate and fungal species and enhance both terrestrial and aquatic habitat.
- Large areas of grass verge and highway corridor are mown 1 to 6 times annually and deliver low ecological values, as do narrow, linear shrub plantings that screen noise walls.

Figure 3.23 Site E. Aerial view of SH16 and Brigham Creek Road intersection. The old highways are single-lane in each direction with very narrow road buffers that have very low ecological values due to regular mowing and/or herbicide use, high noise, and exposure. The new highway stormwater pond (bottom right) is enhanced with native planting, which could be extended south into pasture. Space to the right of the roundabout may be retained for another stormwater treatment device.

Figure 3.24 Site E. Top: Stormwater pond shortly after construction showing overflows and planting. Middle: Inlet to the stormwater pond. Lower: Pond overflow with nearby retained mature trees and coarse wood habitat features. New plantings are mulched with wood chip. (Photos taken October 2012.)

3.3 Case study summary

The SH16/18 case study demonstrates how state highways with high traffic volumes combined with street lighting can dominate road edge-effects and potentially limit biodiversity benefits from extensive ecosystem planting and mitigation associated with the state highway. The most important information that drove final maps of road edge-effects and opportunities for this case study was provided by overlaying Waka Kotahi noise maps and Auckland Council SNA maps with maps of Waka Kotahi-administered Crown land (Figure 3.25). The Waka Kotahi-modelled noise contour maps form a useful base for road edge impacts on ecology values for highways with higher traffic volumes, although lack of data on the effect of noise and light on native animals severely limits the ability to assess the width of the road edge-effects zone associated with traffic noise. Lighting was not included, as the spread of influence of lights along the highways was not able to be determined from maps and is impacted by adjacent lighting and trees. This would be useful to map, with a focus on identifying 'dark' areas where ecological values might be enhanced for targeted native species. The TEC map was important to trigger focus on small, degraded native remnants that may otherwise be undervalued in a desktop screen or not picked up as SEAs in council assessments.

Figure 3.25 Map of SH16/18 case study area showing road edge noise pressures (blue), Auckland Council SEAs (deep red) and Waka Kotahi-administered Crown land (pink).

Where road edge pressures of noise and light are high, as in this case study, ecological benefits can be optimised by identifying areas where these impacts are lowest, such as behind screens and noise walls or bunds. This can influence strategies to enhance buffering of the few remnants present and where new ecological 'stepping stones' are best developed. The small, degraded remnants present in the study area have disproportionately high ecological values, given their high threatened environment classification (red,

< 10% remaining). Key indicators of ecological effects and benefits from buffering should include ‘core remaining’ and ‘core created’, which would direct mitigation of noise and light. Noise and light effects on some SEAs could be mitigated to some extent, especially the northern stream SEA; however, until the extent to which current noise and light degrade the SEAs, selecting the type of mitigation and establishing a value case for mitigation to enhance SEA value are difficult.

Council maps identified remnant native vegetation, but the LCDB v5.0 map was needed to identify areas with deciduous hardwoods or non-native plantation. These need to be included in ecological field assessments because they may have native understoreys, provide habitat for ‘tree species blind’ native animals (eg, insectivore birds, beetles of dead wood, leaf-litter layer invertebrates, and native earthworms), plants (eg, epiphytes and lianes) and fungi. Trees also deliver valuable ecological benefits when they are incorporated into riparian buffers and located to shade streams. Non-native trees should not be cleared unless they are pest plants that have shade-tolerant seedling or unsafe. Such cleared trees should be used as coarse wood to enrich ecological values of new plantings, as long as pest species will not resprout. SH16 demonstrates how opportunities to strengthen ecological outcomes occur along streams when the highway is close enough so that residual fields are too small, too thin, or too oddly shaped to allow economic farming, or are land-locked (isolated). Further ecological enhancement opportunities remain along SH16/18 by converting mown areas to more valuable habitat for native species by establishing shrub and tree species.

Native plantings in the case study areas were ~10 years old and ~5 years post-canopy closure. Variable resilience of these plantings to establishment of light-demanding weeds emphasised the importance of planting for succession. Plantings with a range of native woody ‘colonising’ species (including kānuka, mānuka, five-finger, karamū, māhoe, ngaio, karo, and māpou) that were inter-planted with longer-lived emergent trees (such as karaka, tōtara and pōhutukawa) were generally resilient. Low-diversity plantings, especially those dominated by flax, and/or a high proportion of short-lived native plants (eg, karamū, koromiko, toetoe) appeared more vulnerable to invasion of pasture grasses and establishment of woody pest plant species (Figure 3.26). In such areas native regeneration is supressed and ecological values lowered. Pressures from pest plants in the vicinity of roading projects were severe in some areas. These pressures, especially from shade-tolerant species, indicate that maintaining ecological values in peri-urban and urban areas demands ongoing management. Access needs to be maintained to allow pest plant control, and, in some cases, buffers may need to be established to prevent spread of pest plants from adjacent areas. For example, at Hobsonville (Site A), walking paths and bike paths appeared to be effective buffers to prevent the spread of pest plants.

Where permanent native vegetation is largely absent, as in intensively farmed landscapes, ecological benefits from new highway capital projects are enhanced by complementing initiatives in adjacent land. This approach created much larger areas with more ‘core’ and a greater range of complementary ecosystems at both Westgate (Site D) and Hobsonville (Site A). Such ‘green, biodiversity areas’ are often centred on riparian buffers and constructed stormwater wetlands but are increasingly recognised as delivering benefits to people beyond simply buffering noise and visual impacts of highways. However, lack of data on the ecological values of constructed stormwater treatment wetlands limits the ability to assess value for native animals; data on the impacts of maintenance disturbance and contaminants on terrestrial and aquatic life are needed. However, both human ‘wellbeing’ and ecological benefits are usually enhanced by the presence of native species (especially birds) and tall trees. In contrast, narrow planting that delivers landscape aesthetics or protects noise walls from graffiti provides minimal ecological values. Where such areas are close to traffic and could attract vulnerable native animals such as kererū, they could even increase roadkill.[74]

[74] In the early 2000s, more than 100 kererū/year were estimated being killed along a 2.5 km stretch of SH2 at Upper Hut that was planted with tree lucerne in the 1980s. Since the removal of this prime food source in August 2018, no kererū deaths have been reported (see https://www.urbanwildlifetrust.org/portfolio/kereru-discovery/).

Figure 3.26 SH18 noise wall within low-diversity planting dominated by flax that, in the absence of native tree planting, is likely to be invaded by woody weeds over time. (Photo taken in 2012.)

Figure 3.27 Map of Site A (SH18) showing road edge noise contour (blue), Auckland Council SEAs (deep red) and Waka Kotahi-administered Crown land (pink).

Figure 3.28 Map of sites B and C (SH18) showing road edge noise contour (blue), Auckland Council SEAs (deep red) and Waka Kotahi-administered Crown land (pink). The yellow star identifies Crown land outside the noise contours with potential for delivering multiple ecological values if planted to native ecosystems.

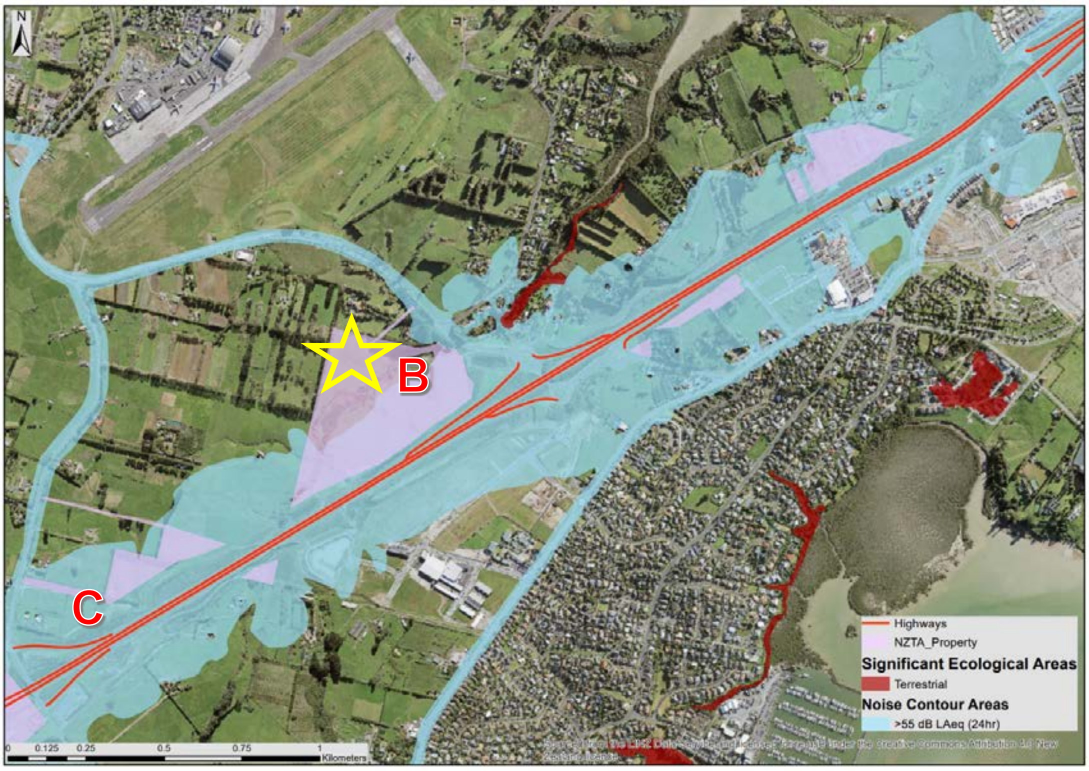
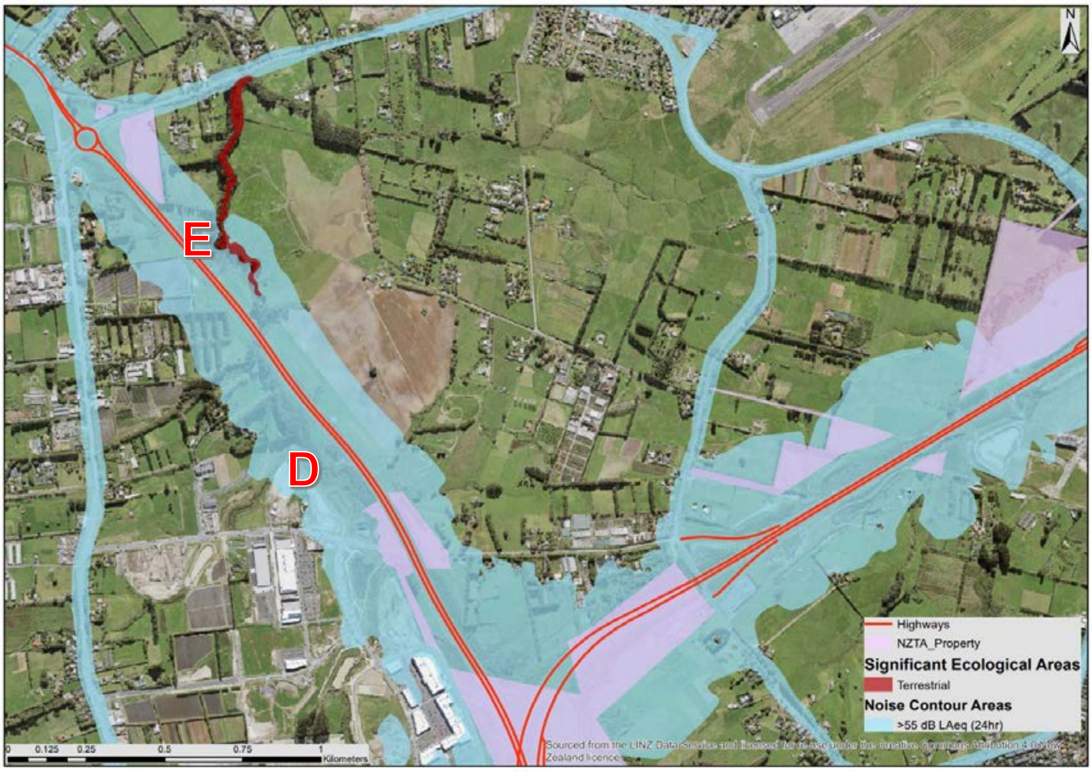


Figure 3.29 Map of sites D and E (SH16) showing road edge noise contour (blue), Auckland Council SEAs (deep red) and Waka Kotahi-administered Crown land (pink).



4 Case study: SH73, Waimakariri Basin, Canterbury

4.1 Purpose

This case study was used to test the efficacy of the draft four-step method for assessing road edge-effects for a rural highway passing through some areas with high-value indigenous ecosystems. In Step 1, sources of data on roads and ecology were identified. Desktop-generated maps and associated checklists were then created (Step 2) and field-checked (Step 3). The field check took about 6 hours and included most bridges, major culverts, and a range of high-value to lower-value ecological areas. A series of photographs from key sites along the case study road effects zone are used to illustrate road edge pressures and ecological values. These sites informed recommendations for measures that could be applied in highway capital and maintenance programmes to reduce the area and severity of adverse edge effects on native biodiversity and/or to generate road edge-effects that benefit native biodiversity (Step 4). Following the case study, the assessment method was refined to create the method described in section 2, which summarises the findings, and repeats some of the figures, in this section.

4.2 Case study overview

State Highway 73 is known as the ‘The Great Alpine Highway’.[75] It runs from Christchurch, Canterbury, through Porters Pass and Arthur’s Pass National Park to Greymouth on the West Coast. With Lewis Pass, SH73 is the main east–west link in the South Island. The Midland railway line and main electricity transmission lines and irrigation channels run alongside the highway for some sections (Figure 4.1). The highway is generally a non-separated single lane in each direction (Figure 4.2) with some single-lane bridges and low average traffic volumes of 1,600–2,000 vehicles/day (AADT), of which 13–23% are heavy vehicles. The case-study section of highway runs through the Waimakariri Basin from Kura Tawhiti/Castle Hill Conservation Area, past Castle Hill Village and Craigieburn Forest[76] Park, to Arthur’s Pass Village within Arthur’s Pass National Park. Two subsections with contrasting neighbouring land uses were investigated at a finer scale in the field (Figure 4.1).

The highway passes through a range of lands managed for conservation, ranging from national park and scenic reserve to recreation reserve, fixed marginal strip, and stewardship land (Figure 4.1). These lands have a wide range of ecosystems of high conservation value, including alpine screes, shrublands and braided riverbeds, which provide habitat for roroa/great spotted kiwi, kea, titipounamu/rifleman, mohua/yellowhead, and whio/blue duck. The area is the southern limit of about 10 plant species, and includes valuable scientific plots such as the ‘Cockayne Transects’, established in 1933 to monitor plant succession after fire. ‘Geo-preservation sites’ identify significant geological formations (11 in the national park itself), and the zig-zag course of the former SH73, now bypassed by the Otira Viaduct, is a recognised historic feature. The highway runs through the Waimakariri Basin, much of which is farmed (Figures 4.3 to 4.5) in ways that has removed native vegetation. Pest animal and plant presence and management vary along the highway. The Arthur’s Pass Wildlife Trust has been intensively trapping predators in the national park’s Bealey Valley for over 10 years, and in the last three years the Trust has been removing Russell lupin, an attractive but smothering weed.[77] More recently, a range of landowners, voluntary groups, and the SH73 network outcomes contractor have removed killed wilding pines, pine plantations, and pine shelterbelts from Porters Pass to Bealey Spur.

[75] https://www.newzealand.com/nz/feature/the-great-alpine-highway/

[76] https://www.arthurspass.com/pdf/craigieburn-forest-park.pdf

[77] https://www.weedbusters.org.nz/what-are-weeds/weed-list/russell-lupin/

Figure 4.1 **Map of the SH73 case study area, Waimakariri Basin (Arthur's Pass National Park to Porters Pass), showing highways, railway, wetlands, bridges and DOC land classifications. The blue boxes identify two sub-study areas that we assessed in more detail, which are shown in subsequent maps.**

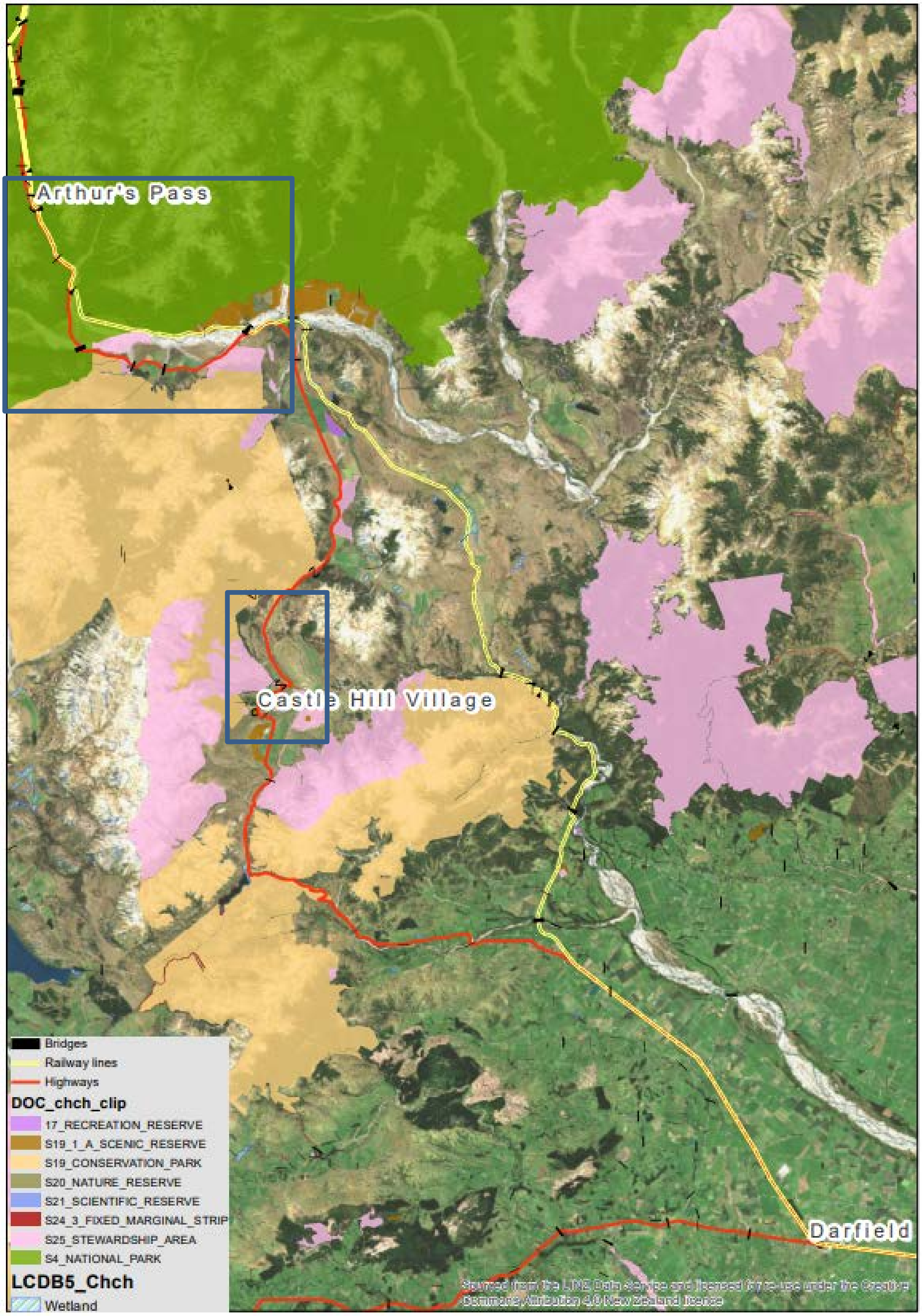


Figure 4.2 Near the summit of SH73 looking down towards Arthur's Pass Village. This section is a barrier to pest plants as the native vegetation is dense and road design minimises exposed soil or gravel by placing edge marker posts on barriers, using concrete dish drains rather than gravel drains, and using retaining walls to minimise the disturbance footprint. (Photo taken April 2021.)

Figure 4.3 The Arthur's Pass sub-study area showing base 100-m and 500-m road edge buffers.

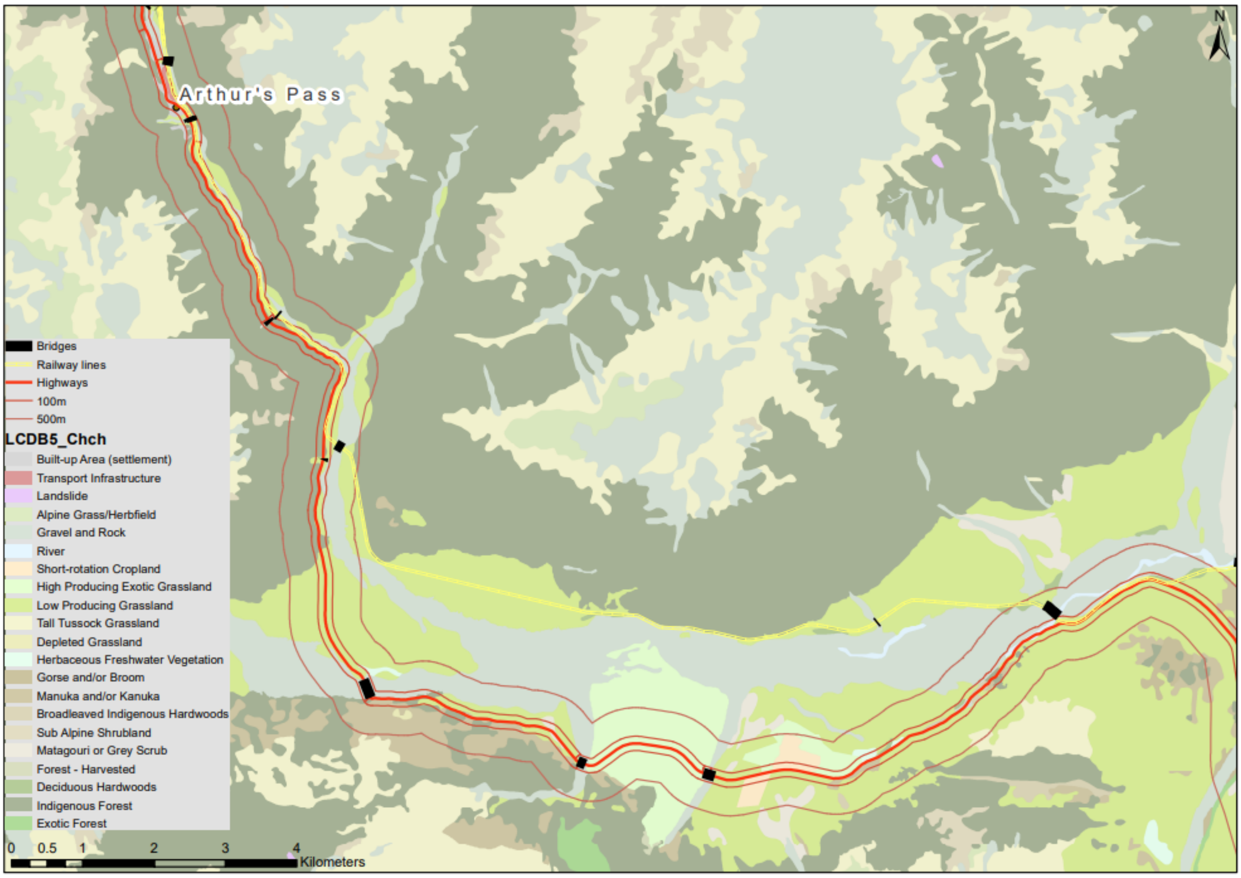


Figure 4.4 **The Castle Hill sub-study area showing initial 100-m and 500-m road edge buffers. Rectangles indicate more-intensively farmed areas with negligible native remnant vegetation due to ploughing and oversowing with non-native species.**

Figure 4.5 The Great Alpine Highway looking towards Castle Hill from Cave Stream Reserve. Here the road passes through extensively grazed farmland. Large road cuts create sparsely vegetated slopes (right). (Photo taken April 2021.)

The Arthur's Pass National Park Management Plan (2007, slightly amended in 2012)[78] identifies an important value of the park is the 'high degree of natural quiet ... despite the park being dissected' (by SH73 and railway). It identifies loss of natural quiet and natural darkness due to road and rail as important impacts from Aickens to Bealey Spur. Closure of some roads within the park is proposed to reduce road impacts. The Management Plan also identifies the greatest threats posed by SH73 and railway are fire and weeds, with fires being 'regular summer events'. A wide range of naturalised plant species align with road and railway disturbance. Of these, Russell lupin is identified as a particular concern. The Canterbury Regional Pest Management Strategy also identifies stopping (Russell) lupin spreading uphill (and upstream) from SH73 as a priority.

A new 5.2 km section of highway and railway was opened in 2017 within Arthur's Pass National Park from near Klondyke Corner around Mingha Bluff to Arthur's Pass Village. This section contrasts with the majority of the highway, being built to current highway design standards with full gravel shoulders and substantial lengths of safety barriers, but without lighting or stormwater quality/volume devices such as engineered stormwater mitigation structures (ponds or wetlands). This new section is expected to be consistent with objectives of the Arthur's Pass National Park Management Plan, which identify the need for 'high quality utility design and maintenance that is consistent with preservation of national park values' (objective 19). A supporting policy is 'to take all practicable measures to protect threatened indigenous plants and animals and their habitat' and 'to exterminate, control or manage introduced plants … and to actively seek to prevent introduction or further spread of non-native plants' (section 6.2.6). However, the Management Plan notes that

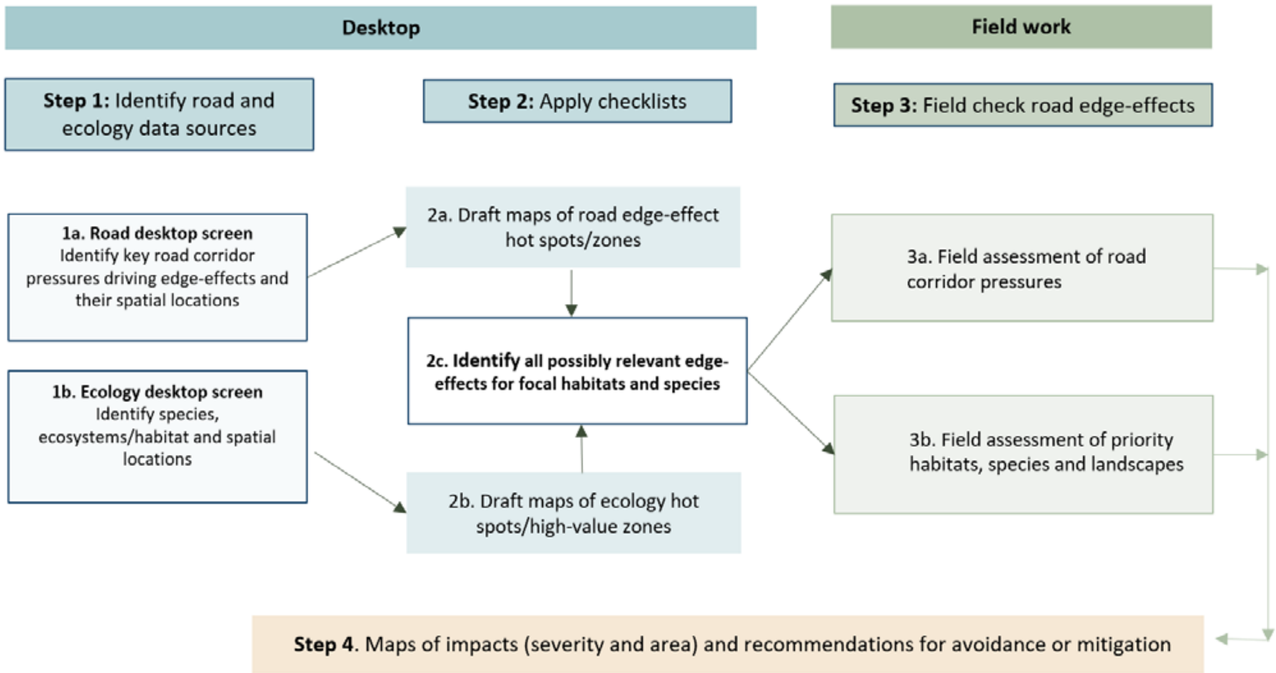
[78] https://www.doc.govt.nz/about-us/our-policies-and-plans/statutory-plans/statutory-plan-publications/national-park-management/arthurs-pass-national-park-management-plan/

'there is very limited funding for weed control'. In this environment, pasture grasses and legumes are also 'weeds' where they suppress native regeneration in exposed soils or smother native herbfields.

4.3 Assessment of road edge-effects

The assessment of road edge-effects is a four-step process (Figure 4.6). The first two steps are desktop analyses, which help focus time spent in the field on areas with potentially high impact and/or high ecological value. The third step is a rapid field verification that delivers information used in Step 4. Step 4 produces maps that identify locations of priority edge effects with site-specific pressures and options for their avoidance or mitigation (ie, adopting the effects management hierarchy). These options are also informed by a spreadsheet that contrasts factors that generally exacerbate or mitigate specific edge effects. This assessment of road edge-effects process does not assess direct loss of habitat due to the road footprint, but it does include degradation of habitat and roadkill as an edge effect. It also focuses on terrestrial effects; however, many common aquatic impacts can be inferred from the assessment of stormwater runoff and points where roads cross watercourses (culverts, bridges) and wetlands.

Figure 4.6 Proposed steps for assessment of road edge-effects for land transport infrastructure.



4.3.1 Steps 1 & 2: Identify road and ecology data

In Step 1a, desktop analyses screen for road pressures that drive road edge-effects on ecological values and the sensitivity of ecological values using the databases listed in Table 4.1 and Table 4.2.[79] The outcomes for this case study are described below. The most significant pressure along the road corridor is habitat modification, mainly related to weeds and stormwater management. Although noise and light also have potential to degrade habitat for native species, no data for New Zealand species are available on which to base an assessment. The potential magnitude of these road effects is influenced by very low ambient (background) noise and light in the adjacent landscape. Roadkill also has the potential to be a significant pressure in future for kea, kiwi, and maybe small forest bird species in areas such as Arthur's Pass National

[79] More detail is provided in section 2.

Park where predation is managed to the extent that it is not the dominant factor limiting abundance of native birds as available habitat is unlikely to be limiting. However, again there are almost no data on which to assess potential impacts.

The severity of fragmentation effects due to SH73 varies with proximity of the road to larger natural barriers such as wide, high-energy rivers, and more extensive barriers created by forest clearance for agricultural production. In some agricultural areas, SH73 may contribute to de-fragmentation. SH73 edge effects are influenced by the ecological sensitivity of adjacent land/ecosystems, which in turn is influenced by adjacent land management, as the highway passes through large areas managed with the primary aim of conservation. Air emissions from vehicles and wind are likely to have highly localised or negligible effects over most of the route, given the narrowness of the road, the road being sealed, and low vehicle numbers.

Table 4.1 GIS layers used to form a draft road edge-effects 'pressure' and 'hot spots' map for field verification.

Map/Layer	Description and rationale
Waka Kotahi road data	• Road centreline* (RAMM_CL#) • Bridges* (detail in Bridge data system) – however, most bridges are easily identified in a ground assessment as they are individually sign-posted • Street lighting – point data on streetlight assets#
Traffic counts	AADT* and % heavy vehicle* (seasonal traffic data and day/night data could be useful refinements for ecological impact assessment)
Waka Kotahi effects data	Noise contours – decibel levels in $L_{Aeq(24)}$# [80]
Waka Kotahi effects data	NO_x and SO_x emissions map* [81]

* indicates data are publicly available through LINZ or Waka Kotahi public website
# indicates data layers provided by Waka Kotahi for this project

In Step 1b, a desktop screen for key ecological values adjacent to the SH73 road corridor reviewed outputs of the spatial databases listed in Table 4.2. The TEC (Figure 4.8, Figure 4.11, Figure 4.12) and PANZ-NZ were the most useful databases, and provided complementary information. Given the large number of protected areas along the highway, it was helpful to classify conservation land into DOC management units[82] (Figure 4.1, Figure 4.9). This allowed differentiation of conservation value, from national park to scientific reserve with high ecological values to stewardship area and local purpose (gravel) reserve – the latter having values that allow excavation of gravel for roading or to retain flood capacity of watercourses. No QEII covenants were identified adjacent to the road reserve. The TEC database showed the majority of ecosystems in the national park and all subalpine areas (north of Porters Pass) through which SH73 passes are 'not threatened', as more than 30% of the original ecosystem extent remains and more than 20% is protected (Figure 4.8). The highest value ecosystems are within terraces and fans of the Waimakariri Basin where native vegetation clearance for farming has reduced indigenous cover to 20–30% of original levels. Ongoing native vegetation clearance in these farmed areas (Figure 4.7) since the TEC indicates such ecosystems are likely to have increased in ecological value. The overall value of these remnant ecosystems may also be considered to be increased by their high public visibility.

[80] $L_{Aeq(24)}$ is time-averaged A-weighted sound pressure level over 24 hours, measured in dB (decibels, the unit of sound).

[81] https://www.nzta.govt.nz/roads-and-rail/highways-information-portal/tools/air-quality-map/

[82] DOC Public Conservation Areas shapefile was downloaded from https://koordinates.com/layer/754-doc-public-conservation-areas/

The LCDB v5.1 map identified non-native forest canopy adjacent to the highway within riparian areas (willow and poplar), around some settlements, and some conservation areas (plantation pines) that may support a range of forest-obligate native plant and animal species (Figure 4.10). The LCDB 'wetland' layer was useful to identify two small wetlands adjacent to the highway.

Table 4.2 Maps and data used to inform a draft edge effects map of biodiversity values for field verification.

Map/Data source	Rationale for use
Land Cover Database (LCDB) v5.1	Maps the dominant vegetation cover. Use to identify the dominant indigenous ecosystems and also the specific 'Wetlands' layer to locate these ecosystems.
Protected Area Network – New Zealand (PAN-NZ)	This identifies land parcels probably managed primarily for biodiversity outcomes. It includes most land managed by DOC and QEII covenants.
Threatened Environments Classification (TEC)	This map uses indigenous plant cover from LCDB v4.1 as a surrogate for biodiversity and identifies areas that are most threatened due to a combination of small residual area and legal protection.[83]
Biodiversity Atlas	Point records of biodiversity, useful to scan for rare and threatened species and includes 'research grade' observations from iNaturalist.
iNaturalist NZ	Point records. The most useful data are 'research grade' observations of fungi, invertebrates and groundcovers, which are not recorded in other databases (other than the Biodiversity Atlas); also useful for native plants in areas with non-native plant canopy, local flowering and fruiting times, and pest plants.
New Zealand Plant Conservation Network (NZPCN)	Comprehensive plant lists for many areas along the highway covering native and non-native species.

[83] Areas with less than 10% and 20% of original ecosystems are priority candidates for avoidance and added suitable buffering to expand the 'core' and protect from damage and weed invasion.

Figure 4.7 Waimakariri Basin land use change 2010–2019 (Harding, 2021). The TEC was published in 2012 so does not consider the blue, green and yellow areas, from which native ecosystems have been removed.

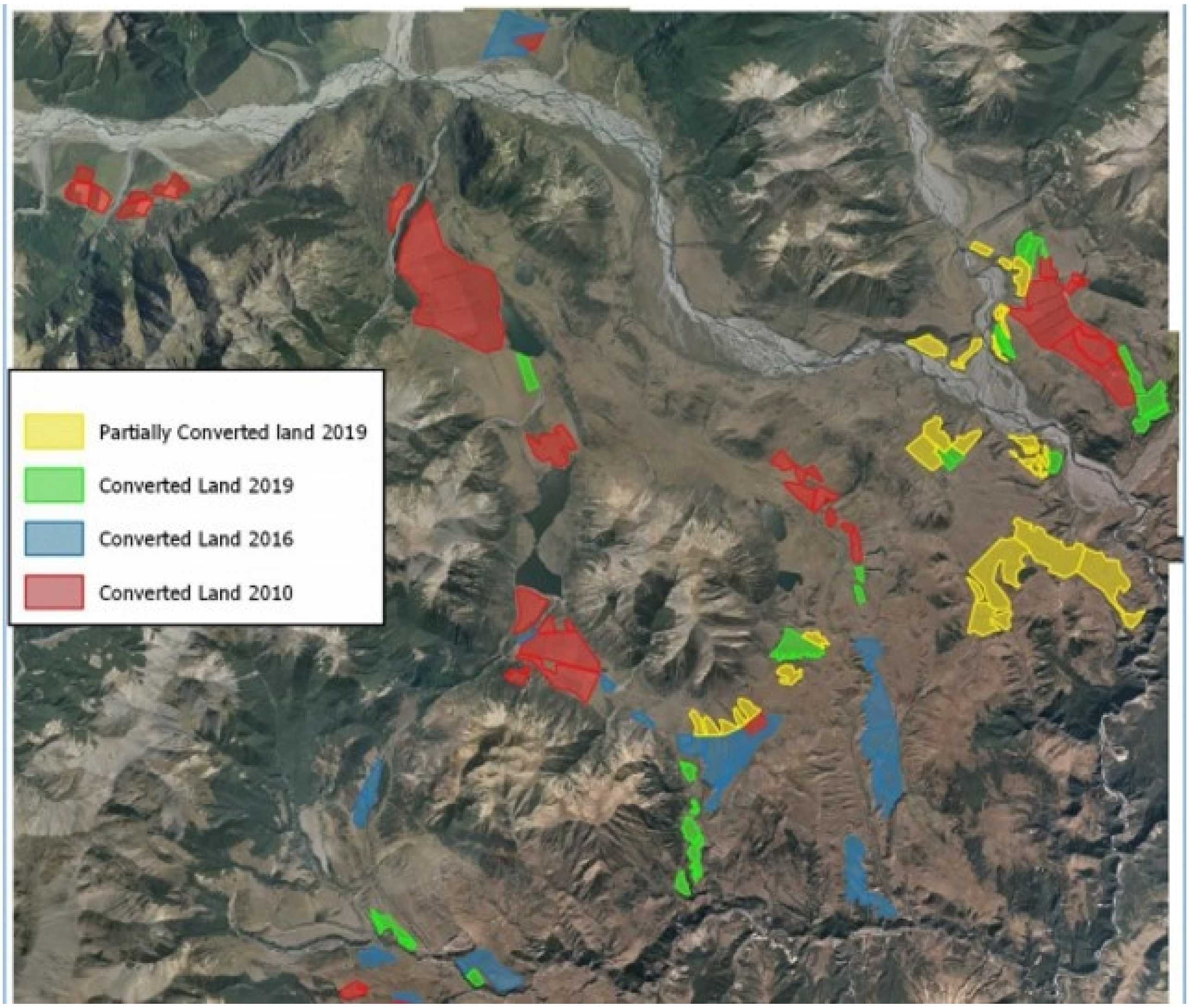


Figure 4.8 Map of SH73 case study area with TEC overlay showing that the majority of ecosystems in alpine areas are not threatened, but high-altitude river valley ecosystems have 20–30% indigenous cover remaining.

Figure 4.9 Ecological values in the Castle Hill section indicated by DOC land class.

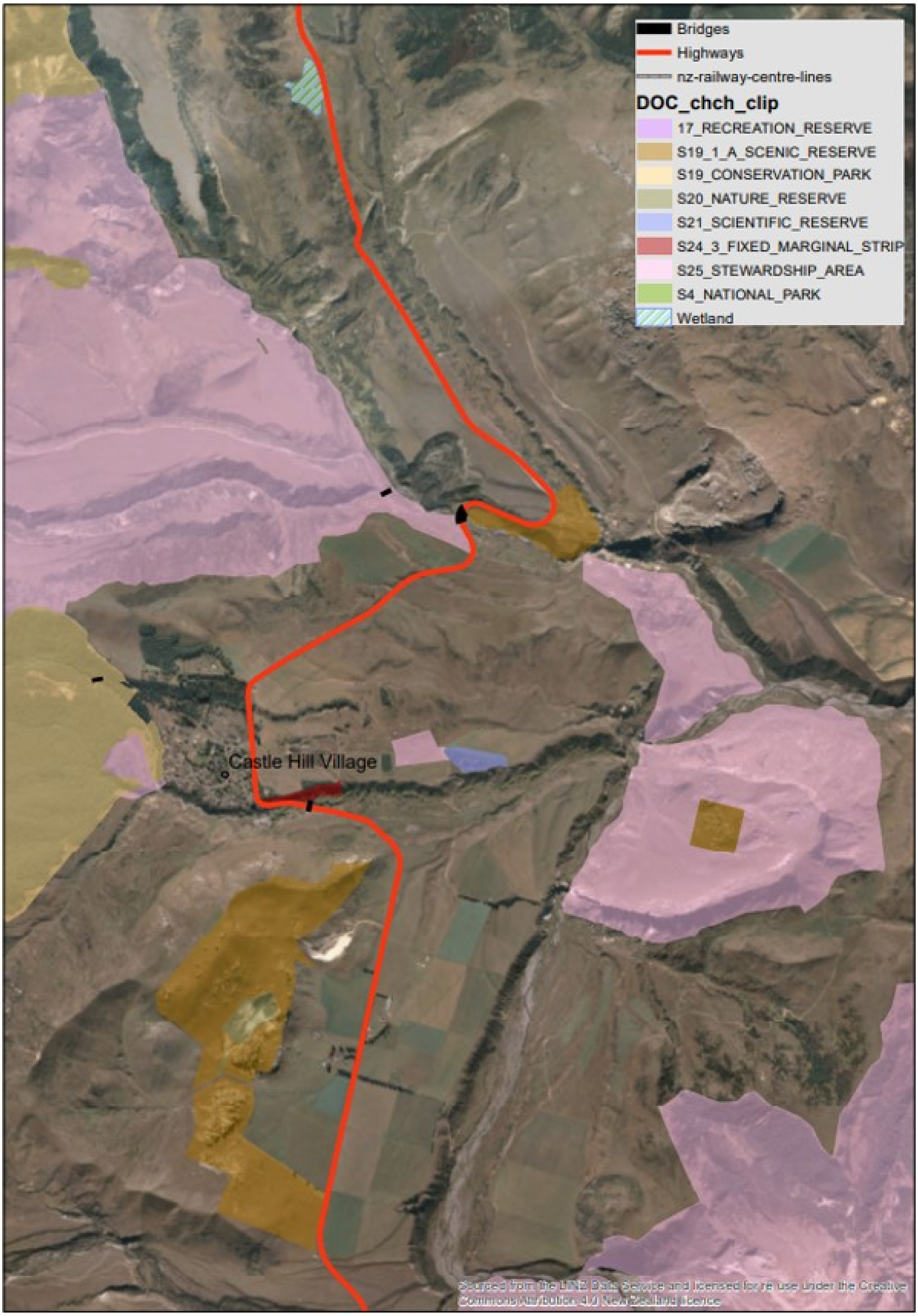


Figure 4.10 Ecological values in the Castle Hill section indicated by LCDB v5.1 land cover classes.

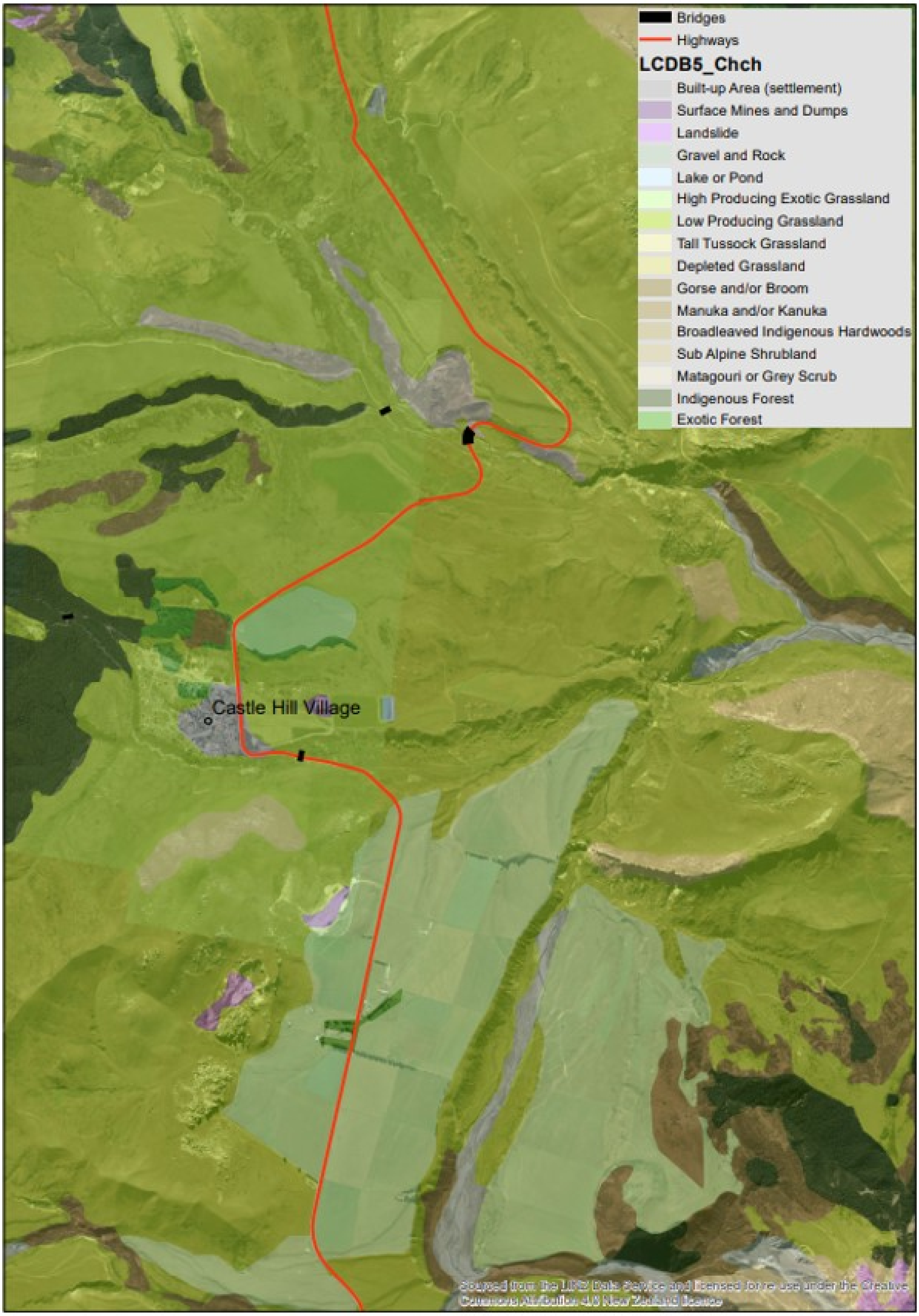
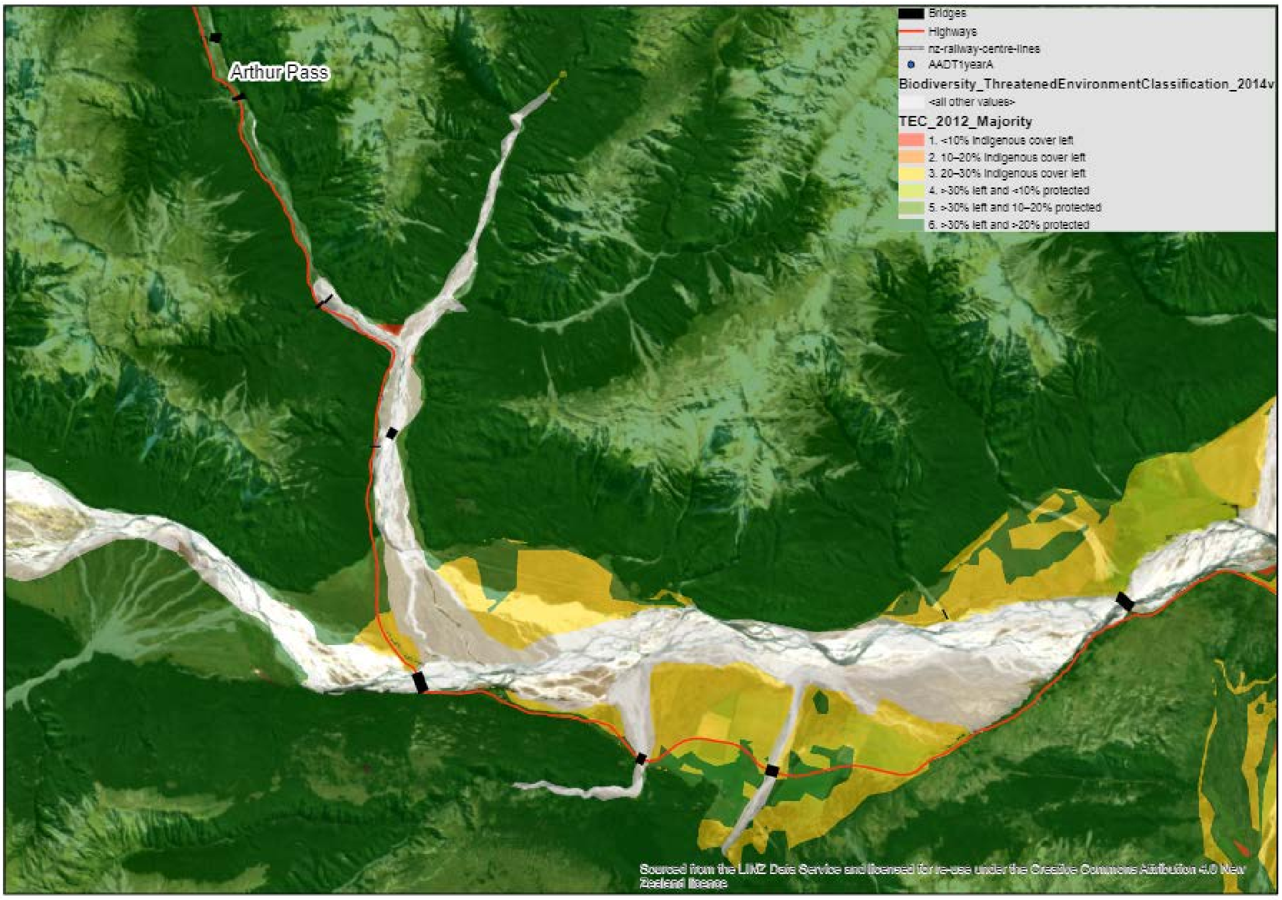


Figure 4.11 Ecological values in the Castle Hill section indicated by TEC.

Figure 4.12 Ecological values in the Arthur's Pass section indicated by TEC.



Localised point data were provided by iNaturalist and the Biodiversity Atlas. iNaturalist was particularly useful because SH73 provides access to large areas of DOC-managed land, including sites where people are likely to visit and record species (Figure 4.13). iNaturalist also identified some locations of individual species of conservation interest, and the monthly frequency distribution of observations was useful for species such as the two mistletoes. The website also has a species list for Arthur's Pass National Park (Figure 4.14), and observations of weeds are linked to a project called 'Invasive plants of Australian and NZ mountains'. The website includes (as yet) sparse data on roadkill through the 'Roadkill New Zealand' project.

However, the NZPCN provides the richest information on plants in the case study area, with over a dozen plant lists available for areas adjoining SH73,[84] including three lists for the Castle Hill sub-study area: Cave Stream by GC Kelly (1971) and two lists for Castle Hill kettleholes by PN Johnson (1993) and GC Kelly (1971). These identify at-risk and threatened species present, including *Carmichaelia monroi* (native dwarf broom) and nationally critical species: *Lepidium sisymbrioides*, *Myosotis colensoi* (Castle Hill forget-me-not) and Castle Hill buttercup (*Ranunculus paucifolius*). Further plant lists cover Arthur's Pass Village to Klondyke Corner (eg, G Jane and G Donaghy (2010), AP Druce (1999) and CJ Burrows (1962 and 1996)). These are particularly useful to indicate non-native species that may colonise earthworked areas, as well as useful native colonising species. Burrows' 1996 list is notable for the range of non-native, woody species, including barberry, *Chaenomeles speciosa,* two cotoneasters and alpine ash (*Eucalyptus delegatensis*).

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[84] https://www.nzpcn.org.nz/publications/plant-lists/plant-lists-by-region/canterbury/

Figure 4.13 iNaturalist locations of observations in Arthur's Pass National Park; green = plants, blue = animals, and pink = fungi observations (extracted May 2021).

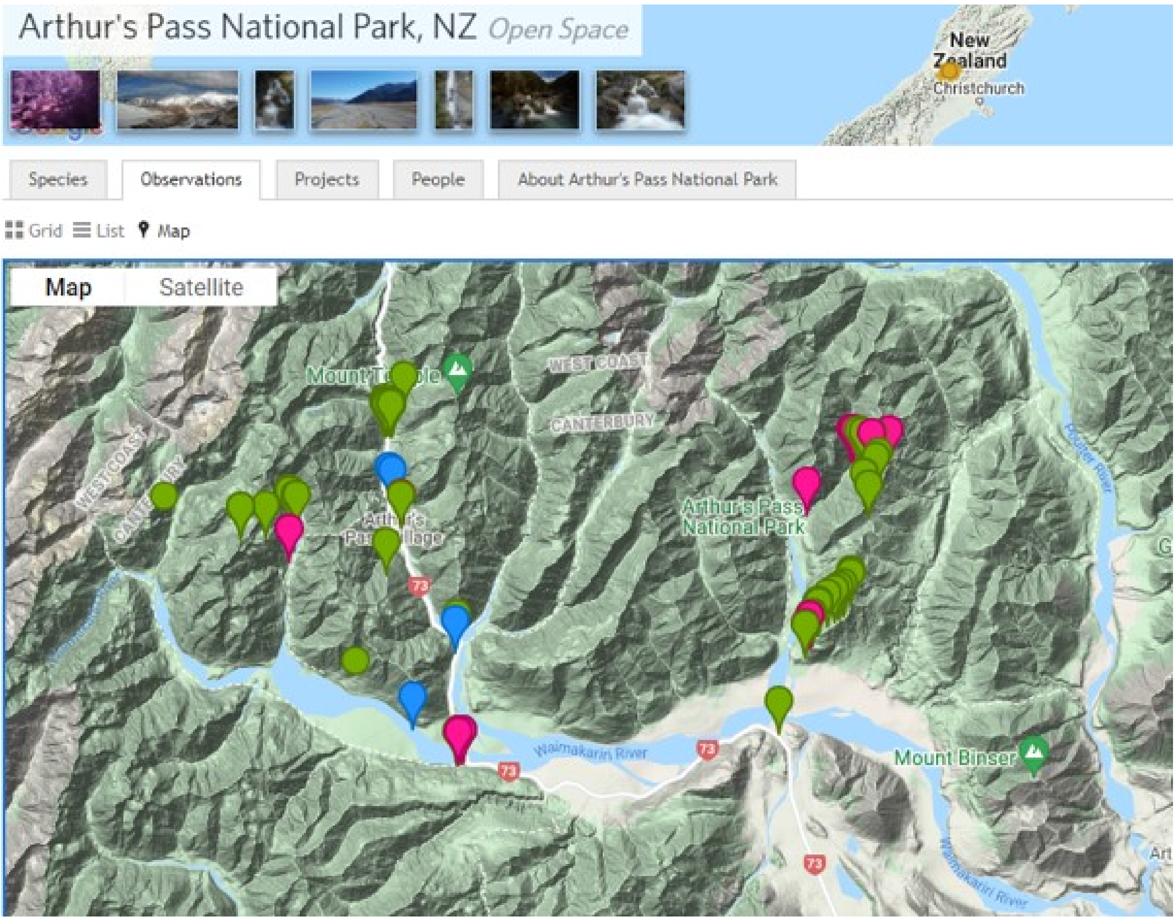
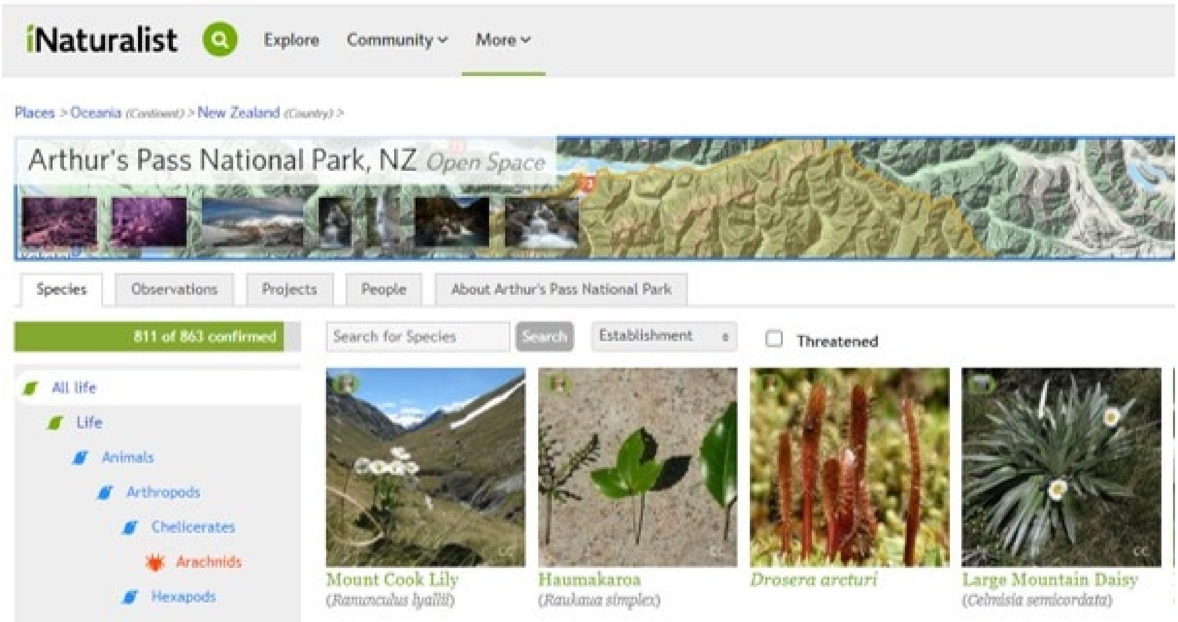


Figure 4.14 iNaturalist screenshots of the Project 'Arthur's Pass National Park' showing information on plant, animal and fungal species recorded by users (extracted May 2021).



The desktop screen of road pressures provided information on probable effects of noise; light; stormwater runoff and hydrology; fragmentation; and people pressures. Each is described below.

4.3.1.1 Noise

Noise related to traffic probably extends hundreds to thousands of metres from the road in places. Although the Waka Kotahi noise contour map shows average noise levels to 55–59 dB on average 25–50 m from the centreline (Figure 4.15), the impact of traffic noise is likely to be magnified in many areas by the ‘high degree of natural quiet’ along most of the highway route identified by the Arthur’s Pass National Park Management Plan, although traffic noise is masked by high-energy water flows in areas near streams and rivers. The Assessment of Effects on Terrestrial Ecology for the Mingha Bluff realignment noted that 5-minute bird counts were not undertaken as traffic noise obscured bird calls (Harding, 2011). The railway is also a significant generator of noise, but train frequencies are much lower than the 1,000–2,000 vehicles/day on the highway.

No engineered noise-mitigation structures were identified along the highway other than a short section of low earth bunds adjacent to Castle Hill Village. The noise contour maps do not appear to include localised noise peaks that can occur on bridges, depending on materials used. Although New Zealand data quantifying the impacts of road-derived noise on components of New Zealand native ecosystems are largely absent, international research indicates it is likely that some native bird, lizard and invertebrate species are present that are sensitive to traffic noise (eg, small forest birds that maintain territories and connections with calls in frequencies that can be masked by traffic, and migratory birds of the open braided riverbeds such as dotterels and wry-billed plovers). In the absence of information on responses of native bird (and invertebrate) species, this case study used the ‘human’ noise effects zone of 55–59 dB mapped by Waka Kotahi.

Data on the noise sensitivity of native species and their locations would inform mapping of ‘reverse-sensitivity zones’, similar to those currently used by Waka Kotahi to reduce impacts on people. This would then guide the location and type of noise mitigation strategies that are used routinely in New Zealand, such as quieter road surfaces and/or lower vehicle speeds at specific times of the day or night or in sensitive seasons (eg, breeding seasons for both migratory birds of the braided riverbeds and forest birds). Replacing noise-permeable safety barriers with solid concrete barriers may be effective, especially where such barriers could also mitigate spread of light from headlights.

Figure 4.15 Narrow noise contours (blue) on SH73 reflect low traffic numbers and extend 25–50 m from centreline on average across the entire Castle Hill sub-study area. The northern bridge could be a site sensitive to noise and light impacts, given low background light, headlights can pass over water, and land is managed for conservation (scenic and recreational reserves).

4.3.1.2 Light

Waka Kotahi records show only a very short section of SH73 has streetlights, and this is in Arthur's Pass Village where other lighting is present. No information was available to indicate if the streetlights are managed to reduce effects on adjacent areas. Given the absence of streetlights, the primary source of light on native ecosystems along SH73 is headlights of vehicles. These can penetrate hundreds of metres across many areas of the highway with short, open grassland and absence of forest, especially on curving sections of road (Figure 4.16). Impacts of road-associated lighting are likely amplified by the absence of artificial light across most of the study area, especially in areas supporting native fauna that are vulnerable to impacts of light.

However, there are few New Zealand studies on the impact of lighting on land birds. Call records by the local conservation trust (www.apwt.org.nz) indicate roroa/great spotted kiwi calls are significantly higher on moonless nights. Light-attracted invertebrates can be adversely impacted by artificial lighting, especially near open water, hence avoiding artificial lighting assets on SH73 that shed light onto waterways (ie, near bridges, lakes and wetlands) should be considered in any future road upgrades. A range of light-mitigation options are used along New Zealand highways, from shielding streetlights to turning streetlights off at critical times of the year and replacing streetlights with alternative forms of lighting or reflective materials. Where space is available, screen planting could be placed on curves to restrict headlight travel across open river flats, and solid bridge edges could be used to reduce light cast over waterways.

Figure 4.16 In the absence of streetlighting, the major sources of anthropogenic lights are small settlements such as Bealey Spur (right) and vehicle lights. Note the large herbicide-sprayed area around the marker post creating habitat for the rosette weed woolly mullein (*Verbascum thapsus*),[85] which has flower stems that typically reach 60 cm height and was first recorded naturalised in 1867. (Photo taken April 2021.)

4.3.1.3 Stormwater runoff and hydrology

Concentrations of contaminants in stormwater runoff from SH73 are expected to be very low, reflecting low road vehicle numbers, but the high-quality, clear and cool receiving waters are highly vulnerable to

[85] http://agpest.co.nz/?pesttypes=woolly-mullein

degradation (Figure 4.17). Small streams are likely particularly vulnerable to high-temperature road runoff in summer. Discharges of effluent from stock trucks are much reduced in frequency following regulations requiring holding tanks; however, localised but significant negative effects have been associated with runoff from vehicle discharges or spills. Such discharges are infrequently caused by vehicle crashes (eg, milk tanker spills and car crashes that generate oil/hydrocarbons and fire-fighting foams). Such effects are minimised when incidents are in areas where discharges flow through adjacent vegetated berms, as the majority of the highway has permeable gravel shoulders, grassed verge, and grassed water table, which together act as informal filter strips (Figure 4.16, Figure 4.20). Effects of spills and high-temperature runoff will be exacerbated in areas with kerb and channel, as this hydraulically efficient drainage provides little mitigation before runoff is delivered to surface receiving waters. Adverse effects from stormwater runoff are linked to agrichemicals used to maintain vegetation clear zones along water tables/drains, culverts and barriers (Figure 4.16, Figure 4.18, Figure 4.19). Even low concentrations of glyphosate are reported as adversely affecting aquatic animals such as New Zealand galaxiids when combined with other stressors (Kelly et al., 2010), and some surfactants applied with glyphosate change skink thermo-regulatory behaviour and possibly slow movement (Carpenter et al., 2016). Effects may be minimised by minimising the area, frequency and toxicity of herbicide applied, especially to water tables and drains.

SH73 is generally characterised by restricted areas of cut/fill and earthworks, consistent with the single carriageway with narrow road shoulders and a focus on minimising the highway disturbance footprint in high-value conservation areas. These features also help minimise changes on hydrology that impact adjacent plants. However, in some cases road (and rail) embankments have blocked water flows, creating rush- and sedge-wetlands. In the vicinity of the recent Mingha Bluff realignment, such induced wetlands were assessed as having moderate to high ecological value (Harding, 2011). This indicates the potential to manage road runoff and drainage to enhance and create ecosystems in areas that are already degraded.

Figure 4.17 Bridge in Arthur's Pass National Park. The bridge has a low impact – its piers are set back from the river, so they do not impact the bed; its narrow width minimises shading; and road runoff discharges to permeable gravels. See Figure 4.24 for a 'road view' of the bridge. Russell lupin (right foreground) spreads downstream. (Photo taken April 2021.)

Figure 4.18 Culverts (blue dots) in the Castle Hill sub-study area. The density of culverts is influenced by slope, being low through cultivated flats and higher on steeper slopes and dissected land from Castle Hill north to Cave Stream.

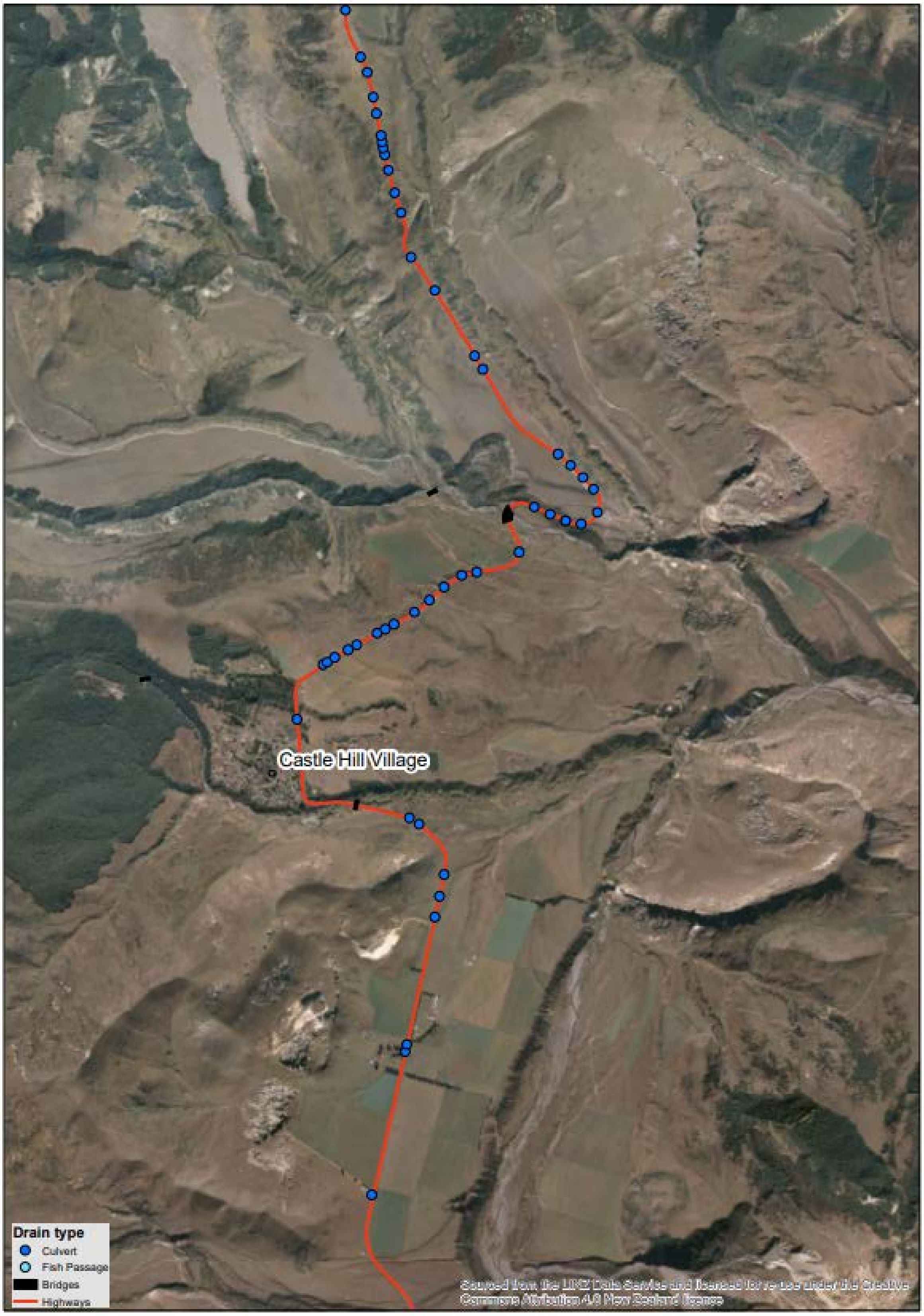


Figure 4.19 Culverts (blue dots) in the northern section to Arthur's Pass Village. The only highway lamps/lights are concentrated in a short section around Arthur's Pass Village (not shown).

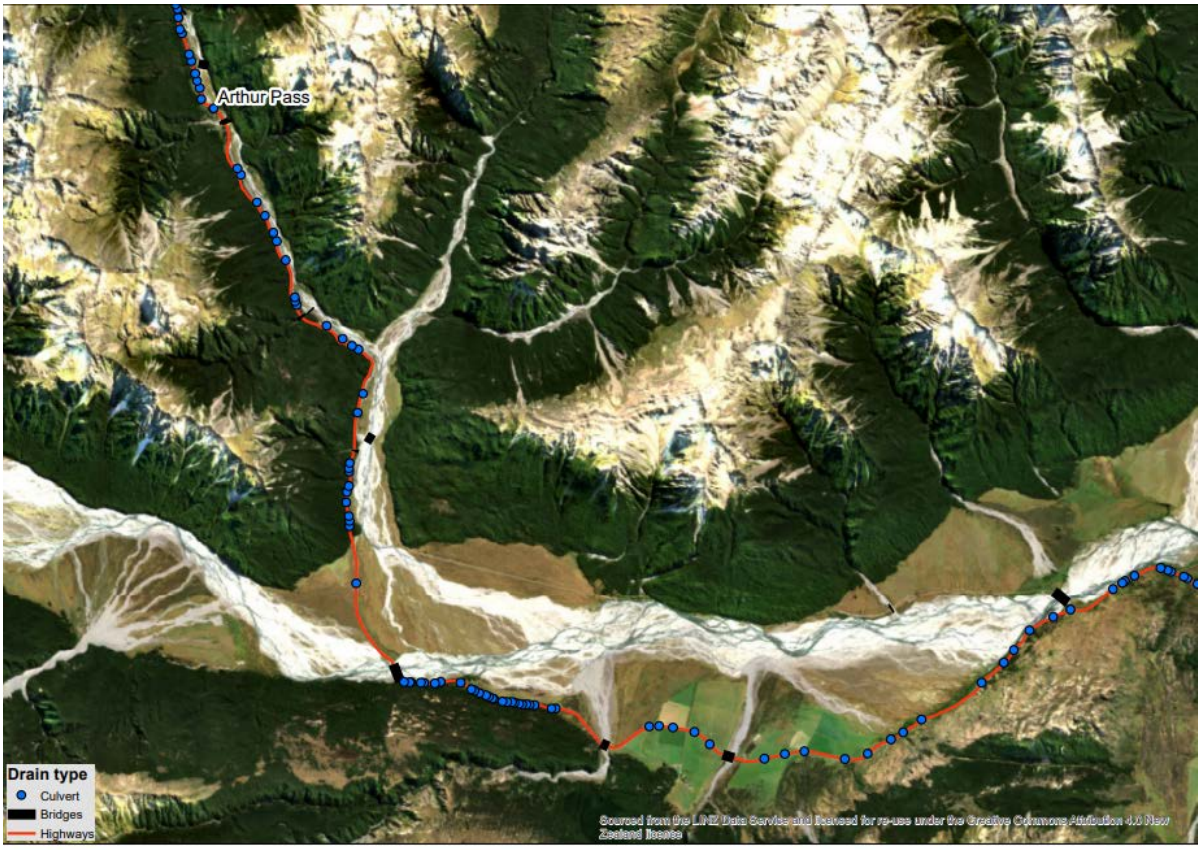


Figure 4.20 New culverts on the Mingha Bluff section of SH73 near Arthur's Pass are designed to cater for intense alpine rainfalls (upper pipe and boulder lining) and year-round fish passage (lower pipe). The new channel is partly shaded by adjacent forest, but has low riparian vegetation cover 3 years after opening, although tutu is establishing (left foreground). (Photo taken April 2021.)

4.3.1.4 Fragmentation and change in value of native habitat

Fragmentation

SH73 probably has the greatest impact on fragmentation of ecosystems where it cuts large areas of relatively intact native vegetation in forested areas – for example, in new sections of road that isolate patches of valley-floor beech forest. Non-forested widths are widest where the road overlaps with the railway and, to a lesser extent, electricity transmission lines. Cleared widths are also widest in areas where road-infrastructure such as parking, pullovers and aggregate stockpiles are present. Tall cut faces can exacerbate fragmentation by preventing animals (eg, poorly flighted birds) moving in the 'uphill' direction. However, the treeless width along SH73 rarely approaches 110 m, which is considered a barrier to small forest birds such as robins (Richard & Armstrong, 2010), while noting there is very little reliable information on the ability of New Zealand birds to cross habitat gaps (Burge et al., 2017[86]). Further, in many places within the national park the effects of fragmentation for small forest birds and poorly dispersing invertebrates are moderated by:

- the proximity of the road to broader, more 'severe' natural barriers such as braided river flats (Figure 4.19)
- in forests, a narrow vegetation-free footprint that is less than twice the height of adjacent trees
- use of bridges with piers set back from riparian zone that create linkages (Figure 4.17, but most notably the Otira Viaduct)
- the road corridor being cut into the landscape rather than being elevated.

Outside the National Park, fragmentation effects of SH73 are dwarfed by the impacts of removal of native ecosystems related to intensive farming across the valley floors (Figure 4.21). In these areas remnant native vegetation and habitats along SH73 could deliver stepping-stones of habitat for some native species. The most useful stepping-stones are where SH73 excludes relatively large areas from farming and stock access due to poor shape, low pasture productivity and/or steep topography in proximity to wetlands or riparian areas. Assessing the potential for these stepping-stones was a priority in the field survey.

[86] A useful summary table is provided in Appendix 3 of https://www.pfhb.nz/assets/Image-Gallery/Burge-et-al-2017-Habitat-availability-for-native-NZ-bird-species-within-the-Cape-to-City-footprint.pdf

Figure 4.21 Remnant native shrubs including matagouri along a very narrow part of SH73 road reserve. (Photo taken July 2013.)

Changed habitat value

SH73 has enhanced biodiversity values for specific species and ecosystems. For example, both red and yellow mistletoes are more frequent along the highway edge (Harding, 2011). The reason may be four-fold:

- road edges have higher light levels
- activity of pollinating birds is higher along edges (Norton, 1997)
- edges tend to have larger trees (and the lower valley slopes where SH73 runs has larger trees)
- possum browse may be lower along road edges.

Road and rail construction has also created naturally uncommon habitats, including small wetlands where water flows are blocked, and rocky outcrops or gravel talus slopes on some fill embankments. For example, some open, stony sites support populations of *Coprosma acerosa*, which were expanded by planting and translocation during the recent Mingha Bluff realignment (Harding, 2011). *C. acerosa* has been successfully established using protective sleeves against intensive browse pressure from hares (Figure 4.22). Control of hares near the road is difficult; shooting is the most effective method.

Figure 4.22 Mitigation planting of *Coprosma acerosa* between highway and railway. (Photo taken April 2021.)

The SH73 roadside plant communities generally reflect national patterns of non-native and native plant frequency in road corridors. Where the highway passes through native vegetation, the berms often have a lower proportion of native plants than the surrounding landscape, but the reverse occurs on berms in pastoral areas (Lázaro-Lobo & Ervin, 2019; Overton et al., 2002; Figure 4.21). Degraded habitat values due to weed invasion are most severe where the weeds smother lower-growing native plants, and where weeds spread from roads down water tables into streambeds and braided river habitat. In these areas, taller legumes such as Russell lupin, gorse and broom degrade habitat for birds of braided riverbeds by providing cover for predators. In agricultural areas, and near the three small settlements, palatable pest plants have spread onto roads and then spread along the road corridor due to the lack of control by browsing stock. This pattern is seen near Castle Hill for a variety of conifer weeds, willow, hawthorn, lupin and broom. Many of these pest plants are still in the early stages of invasion into this landscape. Without effective control of these weeds within the whole width of the road corridor, adverse effects are likely to increase over time.

Regular disturbance along SH73 – including agrichemical applications around road edge marker posts, signs, water tables and some barriers – creates environments in which some non-native plants can persist and potentially build up populations. These weeds can then spread into suitable disturbed habitat in adjacent areas, such as along tracks. Mowing berms also creates a narrow strip of disturbance, but along most areas of SH73 mowing maintains a cover of short, drought-tolerant grasses dominated by (non-native) browntop. These stabilise the soil and prevent establishment of a range of non-native herbaceous species that colonise sprayed areas (eg, Figure 4.17). In discrete areas, mowing maintains native herbfield containing species such as *Muehlenbeckia axillaris* by reducing competition from taller plants. In this alpine environment, road-related disturbance also includes spreading and sweeping of grit in winter. This can physically damage plants or bury them. Calcium magnesium acetate (CMA) is used in some road sections[87] but extensive, long-term monitoring in the Central North Island has not detected adverse effects on soil or plants.

[87] Common grit and CMA treatments in New Zealand are summarised in a 2011 article in *NZTA Research*: https://www.nzta.govt.nz/assets/resources/nzta-research/docs/nzta-12.pdf

Within forests, increased exposure and lower humidity along road edges reduces habitat value for plants, fungi and animals that require high-humidity, shaded, sheltered conditions. No data are available on the distance of these effects for SH73, but effects are expected to be greatest at the upper edge of cut batters, especially where instability leads to erosion of edges removing plants. In isolated places this has included death of larger, older trees, which can be important habitat. Such ‘edge effects’ in forested areas are moderated where the road is incised, narrow, shaded by topography or taller trees on the northern side of the road, and winding (to stop wind tunnel effects) (Figure 4.23, Figure 4.24).

Figure 4.23 Fragmentation and edge effects of SH73 in alpine shrubland is limited by constraining the non-vegetated area using narrow lanes with safety barriers and retaining walls. (Photo taken July 2013.)

Figure 4.24 New bridge and road construction that minimises impacts of fragmentation and weed invasion with forest generally retained close to the road edge. Tutu and beech seedlings are naturally establishing along the exposed edge (foreground). (Mingha Bluff realignment; photo taken April 2021; the bridge is also shown in Figure 4.17.)

Figure 4.25 Shelter belts of pines have been cleared from farmland on both sides of the road, but some pine seedlings continue to establish along the road edge, and are controlled by the SH73 network outcomes contractor. (Photo taken in April 2021.)

Figure 4.26 The road footprint in Arthur's Pass National Park is reduced by using vertical rock walls and reduced margin with concrete kerb. The vertical wall could also be a barrier to kiwi. (Photo taken in April 2021.)

Figure 4.27 New road construction has non-forested edges that exacerbate fragmentation and support invasive weeds such as Russell lupin. (Mingha Bluff realignment, photo taken April 2021.)

4.3.1.5 People pressures

People exert both positive and negative pressures on biodiversity within the SH73 case study area. These pressures and their outcomes influence how SH73 edge-effects on both conservation areas and farmed areas may change over time. SH73 provides access to adjacent conservation lands. Pressures from people are concentrated at these access points, especially where parking or camping is available. Such places have increased vulnerability to fire (Figure 4.28) and weeds, particularly fruit (Figure 4.29) and pretty flowers such as Russel lupin. Discarded fruit is a source of sparse trees that are simple to remove, but have been allowed to persist along the highway. People are increasingly likely to exert positive pressures. For example, the Arthur's Pass Wildlife Trust[88] helps manage pest plants and animals near SH73, the railway, and in the wider landscape. The Trust manages over 1,500 traps targeting stoats, weasels and rats. Positive actions by owners of adjacent land (and DOC) have included removal of pine shelterbelts and plantations within farmed areas. This has greatly reduced the propagule pressures onto SH73 (Figure 4.25).

An increasingly important effect of road users is roadkill. Visible roadkill along SH73 is dominated by non-native animals such as possums, rabbits/hares and hedgehogs. Brockie et al.'s (2009) study indicated possum, hedgehog and rabbit roadkill could be expected to increase if traffic densities increase from the relatively low ~2,000 vehicles/day up to 5,000 vehicles/day. Possums, rabbits and hedgehogs are scavenged by harrier hawks. Young hawks in particular are vulnerable to being killed themselves while feeding on roadkill, and although the April field survey was past the peak vulnerability time, one dead hawk was recorded near a dead possum (and a dead cat) near the Porters Pass ski field entrance.

While populations of harrier hawks may benefit from roadkill overall, populations of threatened native birds with low productivity could be adversely affected. DOC reported four kea deaths in Arthur's Pass roadside and ski field carparks in 2017.[89,90] Along SH73, a kea was photographed pushing a snowball across the highway,[91] and others have been photographed exploring road machinery (Figure 4.30). In addition to permanent signs (reported as generally ineffective by van der Ree et al., 2015; Figure 4.29), temporary flashing warning signs have been used to alert drivers to kea. Harding (2011) noted seven roroa/great spotted kiwi with territories on the west side of Bealey Valley, the area that is bisected by SH73. The Mingha Bluff realignment project consequently proposed using temporary fences to exclude kiwi from the construction area and tracking of individuals with radio transmitters during construction. No records were found of kiwi deaths.

Unlike kea and kiwi, small roadkill is unlikely to be recorded as it is difficult to see during a car-based survey and rapidly decomposes or is quickly scavenged. Roadkill of tauhou/silvereye, pīwakawaka/fantail, kahukura/red admiral butterfly, tūī, riroriro/grey warbler, kōtare/kingfisher, korimako/bellbird, kapowai/giant dragonfly, titipounamu/rifleman, kererū and ruru/morepork are recorded by iNaturalist across New Zealand, so are potentially also killed on SH73. In the absence of data on absolute numbers of these birds in Arthur's Pass, any impact on their populations is not known. However, native roadkill would likely increase with increased traffic volumes and if populations near roads increase in response to predator mammal control in the broader landscape.

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88 https://www.apwt.org.nz/

89 https://www.stuff.co.nz/environment/96680765/power-poles-and-cars-to-blame-for-recent-spate-of-kea-deaths-near-arthurs-pass

90 https://www.doc.govt.nz/news/media-releases/2017/drivers-urged-to-slow-down-for-kea/

91 https://www.stuff.co.nz/environment/96635209/smart-cookie-kea-makes-a-snowball-in-arthurs-pass-canterbury

Figure 4.28 Fires are an adverse effect on biodiversity along roadsides in the Waimakariri Basin. One of two fire places at a rest area uses silver birch kindling from nearby trees and wilding pine wood and cones. (Photo taken April 2021.)

Figure 4.29 Left: A road sign raises awareness of kea to reduce roadkill. Right: A wild apple tree on the SH73 roadside probably established from a discarded apple-core thrown out a car window. (Photos taken April 2021.)

Figure 4.30 Kea inspecting machinery at a grit stockpile east of Otira Viaduct. (Photo taken July 2013.)

4.3.2 Steps 3 & 4: Fieldwork and recommendations

The objective of the field assessment was to review (and verify) biodiversity pressure, threats and opportunities identified by desktop mapping and to check threats and opportunities that are difficult to detect at the scale of regional/national maps (~0.5–1 ha). Threats that were targeted during the field survey included pest plants within the corridor, especially ‘outliers’, and plants on neighbouring land that may ‘jump’ onto the highway corridor. The road corridor in intensive agricultural areas was examined to find potential corridors or nodes of native plants that were too small to see on maps. Localised effects of stormwater were assessed by observing connectivity between road water tables and surface waters, and road edge maintenance treatments, particularly herbicide. Each bridge and a selection of culverts were visually assessed. These are key pressure points; pest plants can establish and spread downstream, steep banks often allow weeds to establish, road runoff enters surface waters, and roadkill is often concentrated in these places. Areas where railway and transmission lines were co-located were also assessed.

The field assessment identified where road effects pressures and ecology features combined to form areas and hot spots of biodiversity impact and/or hot spots of opportunity. Weed pressures were consistent in both highly intact conservation lands and depauperate farmland. Four areas were identified. These represent two opportunities for biodiversity enhancement and two biodiversity threats to mitigate, as below:

A. Reducing weed pressure – targeting outliers (Figure 4.31)

B. Creating passive barriers to pest plants (Figure 4.33)

C. Fragmentation of beech forest and barriers to native fauna in a national park (Figure 4.27)

D. Retaining and enhancing wetland and riparian nodes in depauperate areas (Figure 4.34)

4.3.2.1 Reducing weed pressure – targeting outliers

The field survey identified ‘outlier weeds’ able to develop dense populations within the road corridor and then ‘springboard’ into adjacent lands when suitable disturbance or conditions, such as cessation of grazing, occurs. 'Outlier' weeds do not usually exert negative pressure on biodiversity now because populations are low, but they are likely to have large impacts in the future. Such weeds are likely to have the greatest adverse effects on roadsides adjacent to high-value conservation areas. Within both conservation areas and farmed landscapes, priority areas are where weeds (eg, broom, Russell lupin, mimulus and willow) move into water tables and from these are washed into natural watercourses and onto river floodplains. Effects are greatest where domestic stock browsing or humans do not control these weeds in the adjacent landscape. For example, Arthur's Pass volunteers are removing weeds west of Klondyke Corner, including in the road reserve, and Flock Hill Station has recently replaced pines and willows with native plantings adjacent to the highway.

The field survey showed the location of pest plant populations is influenced by road design and road maintenance methods. Three key places in the road corridor are vulnerable to weed establishment: open cut faces, sprayed areas and infrastructure storage areas. In open cut faces or steep fill slopes where a dense cover of grasses or native plants does not develop, ongoing weed control is needed – for example, large cut batters into Broken River terraces either side of access to the Cheeseman ski field in which pines, lupin and broom continually establish. Road design should avoid creating such areas, and current management should eliminate adjacent source areas where feasible.

The second place where pest plants establish is bare areas created by agrichemical use that are not deeply shaded by trees. Most of these areas are around road edge marker posts set into gravels or soil, and at culverts. Weeds establishing into such sprayed culverts can readily spread downstream. Steep, denuded areas are also more vulnerable to erosion and movement of agrichemicals into surface waters. The specification for 'vegetation-free zone' around edge marker posts is a 30 m length. In April 2021 three locations between Castle Hill and Bealey Spur had denuded zones around marker-post zones that were 5–11 m long, indicating substantial potential to reduce herbicide-treated areas. Bare areas could be further reduced by not spraying around signposts (as they are not required to be vegetation free), mowing (which maintains a dense grass cover), removing redundant edge marker posts, and ensuring edge marker posts are consistently placed at the minimum required distance from the edge white line.

The third area of road corridors that is vulnerable to weed establishment is roadside storage/maintenance areas. The road survey found effective weed control at the Deaths Corner grit stockpile, with only native species colonising edges of stockpiles, but a variety of weeds colonising the joint railway/highway work area at Mingha Bluff. Reducing the footprint of both places by using boulders/rock (natural features) to define edges would reduce weed establishment and ongoing maintenance.

Within farmed areas, priority weeds within the road reserve are those that are controlled by browsing in adjacent farmland because such weeds can be 'stopped' from spreading. The following weeds and hot spots were observed in the SH73 corridor:

- Russell lupin and broom adjacent to Korowai-Torlesse Tussocklands Park and Broken River, and a single heather plant on the old SH73 road alignment above the Deaths Corner lookout
- *Sedum acre* spreading from Porters Pass roadside into western Korowai-Torlesse Tussocklands Park and from Cave Stream reserve onto the highway
- apple, cherry/other stonefruit from discarded fruit
- pines and hawthorn spreading from shelter belts on adjacent properties.

Work reports on the Arthur's Pass Wildlife Trust website[92] indicate weeds in the vicinity of SH73 near Arthur's Pass Village include cotoneaster, lotus, lupin, gorse, male fern, foxglove, ragwort, *Verbascum*, viper's bugloss, thistle, blackberry, briar rose and willow. Unusual outlier weeds were planted at the rest area

[92] www.apwt.org.nz

at Porters River (Figure 4.31). Rest areas established prior to about 2000 often included non-native trees that are now recognised as invasive, such as the five now-mature silver birch (*Betula pendula*). These pest plants should be removed to prevent their spread and their use as firewood. Recently upgraded DOC carparks at Cave Stream and Kura Tawhiti/Castle Hill Conservation Area provide indicative templates for pest tree replacement with native landscaping. Such strategies could benefit other rest areas on SH73, and nationwide in areas with high natural environmental values. Upgrades also provide an opportunity to remove other pest plants that may be present in the adjacent landscape (eg, briar rose and apples at Porters River). This relatively large rest area could become a node for palatable native plants that are browsed from the adjacent farmed landscape, if hare browse can be controlled, although some heavily browsed coprosmas, *Myrsine divaricata, Muehlenbeckia axillaris* and matagouri are present. This location also has potential as a place to efficiently kill mammals that may use the bridge, as a wild cat and dead possum were noted during the field assessment (Figure 4.32).

Figure 4.31 Porters River rest area with silver birch, mown base, and native shrubs on unmown batters. (Photo taken April 2021.)

Figure 4.32 Roadkill is more common at approaches to bridges. (Photo taken April 2021.)

Figure 4.33 A priority area for reduction of length of herbicide spray around marker posts in Arthur's Pass National Park (Photo taken April 2021).

4.3.2.2 Creating passive barriers to pest plants

Weed removal is more effective when re-invasion is prevented. The desktop maps were used with the field survey to identify bridges where spread of pest plants and potentially animals is most effectively slowed. Such barriers are most effective where weed survey and control is done by DOC or the community, as at Arthur's Pass National Park, and natural barriers to establishment and spread of pest plants can be reinforced. Natural and designed barriers have an absence of suitable places in which seedlings can establish. Along hundreds of metres of SH73 road design features prevent nearly all seedlings establishing. Gravel shoulders are replaced with seal that extends to concrete dish drains (instead of earth ditches), and dense native vegetation maintained to the road edge. Retaining walls reduce the slopes above the wall to an angle that can maintain a dense cover of native plants that excludes weeds. 'Fill' retaining walls are tall enough to ensure deep shade is maintained by adjacent shrub or forest canopy, as most weed species require high light environments. Such work needs to be supplemented enough to allow access for monitoring and removal of the occasional pest plant that establishes. In the case of palatable pest species, removing palatable pest plants from the road corridor can stop these plants using the road corridor to 'move' because pests are generally removed by stock (or hares) when young. This applies to most broom, gorse and willow.

4.3.2.3 Fragmentation of beech forest and barriers to native fauna

In this case study, desktop mapping was useful to show where vegetation and ecosystems were fragmented, including wetlands, but the maps needed to be supplemented with field assessment to identify where potential barriers were exacerbated by steep cuts and fills, or moderated by high and long bridges that allowed ground contour and vegetation to flow under the bridge. Aerial maps were not recent enough to show the footprint of the relatively new Mingha Bluff highway section, which in most areas was substantially wider than the old highway. Application of footprint-minimising techniques as described above to minimise sites for pest-plant establishment was generally limited.

However, this new highway section included 'defragmentation'. In some places 'outlier' beech trees were retained and then reconnected to adjacent forest using planting. Importantly, the project also retired sections of highway by setting up conditions for natural regeneration of forest – that is, generally weed-free, loosened, and somewhat-roughened gravel surfaces. After about three years, native tutu and koromiko shrubs are establishing densely along some edges, with 1–5-cm-tall beech seedlings concentrated within about 1.5–2 m of the old forest edge. Continued regeneration will require control of smothering groundcovers such as lotus, clovers, Russell lupin, and taller pasture grasses in some areas. Outcomes could have been enhanced by judicious use of cleared wood to create more sheltered microclimates, rougher surfaces, and by translocating beech seedlings up to 2 m tall from forest edges (as has been done at Castle Hill Village).

4.3.2.4 Retaining and enhancing wetland and riparian nodes in depauperate areas

Ground mapping identified opportunities to create indigenous wetland and riparian nodes in the depauperate farmed road corridor. Where SH73 curves by wetland or riparian areas, steep topography, and poor shape/lack of access/stock danger/low stock food value creates areas unable to be used for farming. Four areas were identified, and are described below, from east to west (Figure 4.35):

A. Rest area at Porters River (Figure 4.31), discussed in section 4.3.2.1 above. Removal of non-native trees would ideally extend to adjacent riparian area.

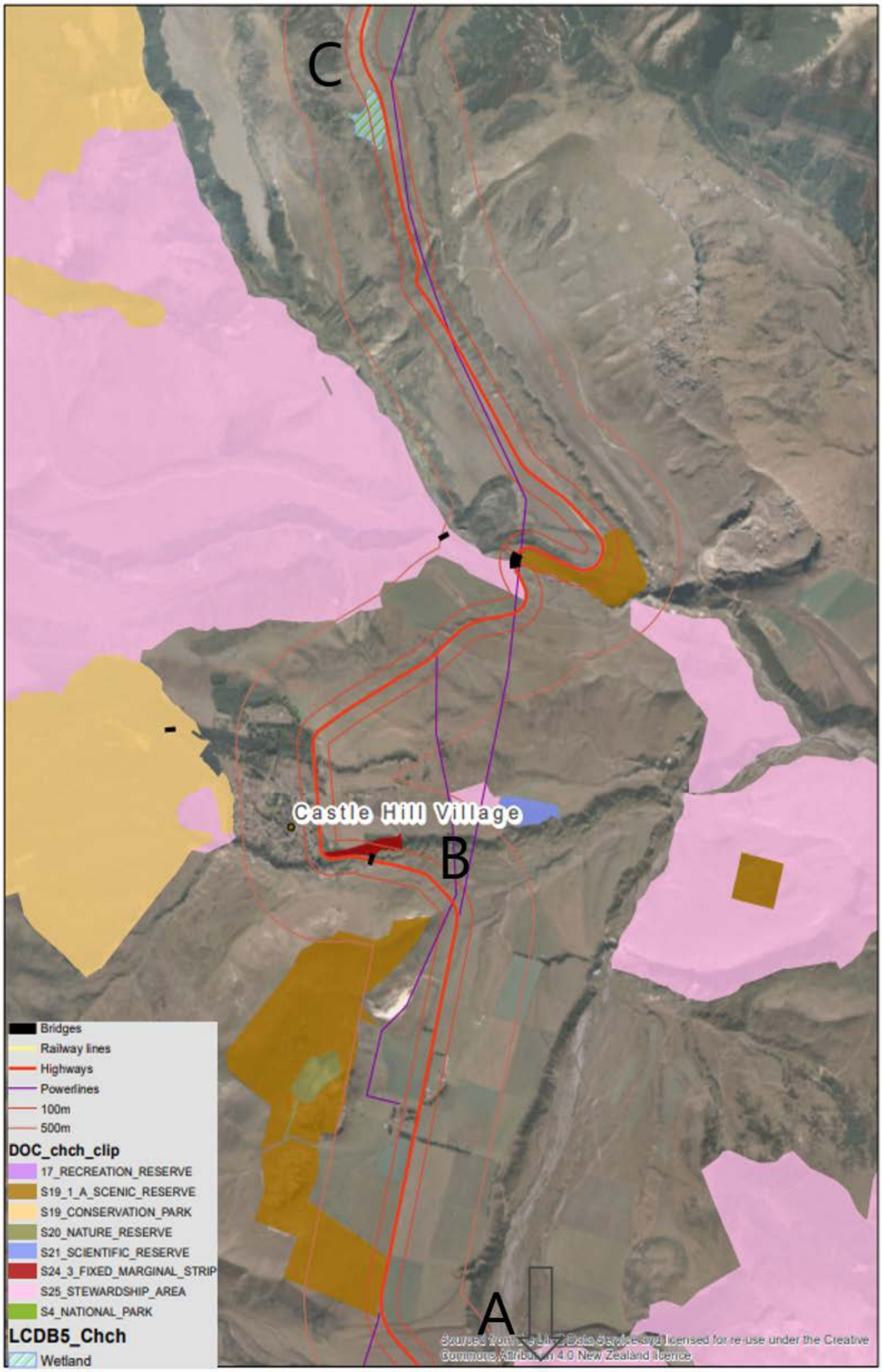
B. Bridge #942 over the Thomas River immediately east of Castle Hill. A concrete channel along the cutting into the terrace scarp diverts spring and road runoff to a willow-covered wetland.

C. Culvert with riparian scarp west of Cave Stream and immediately east of terraces cleared of pines with gravel stockpile area (before Lake Pearson). This area has sparse weeds (mainly briar roses) and would be protected by removal of sparse upstream willow (Figure 4.34) and by defining the gravel stockpile area and vehicle access points to allow native species to revegetate.

D. Culvert and wetland in combined highway and transmission corridor east of Wilderness Lodge. This area is contiguous with an adjacent ungrazed terrace landform across which road and pylons pass, and within which broom has been sprayed with herbicide. Removal of remaining broom, briar rose and wild apple would build on recent removal of most upstream scattered non-native trees, although some willows remain. This may need joint management between two government agencies.

Figure 4.34 Road corridor option for enhancement of biodiversity values in a depauperate agricultural landscape where incised riparian areas on a curve create a significant ungrazed area large enough to form a node. (Photo taken April 2021.)

Figure 4.35 Location of three of the four potential biodiversity nodes along SH73 that could be used to mitigate impacts on biodiversity by enhancing natural areas within depauperate landscapes.



4.4 Case study summary

The SH73 case study demonstrates how road edge-effects are strongly influenced by characteristics of the road and the adjacent environment. The latter was explored by comparing the new, 'upgraded' state highway through Mingha Bluff, which had the same traffic volumes as adjacent old state highway but substantially different edge effects, both positive and negative. More negative edge-effects were linked to a wider cleared footprint with greater cut and fill areas, unrehabilitated infrastructure storage areas, and greater paved widths that together increased areas of non-native plants, volumes of stormwater runoff, hydrological impacts, and fragmentation effects. However, defragmentation by initiating rehabilitation of redundant sections of road partially compensated for the fragmentation effect.

Characteristics of the adjacent environment also strongly influenced the direction and size of road edge-effects – for example, in farmed areas where PAN-NZ maps show a low proportion of native ecosystems remain. Here, road edges with remnant natural ecosystems can support native biodiversity. Specific locations are defined by changes in contour that create land parcel of low economic value (poor access) and frequently adjoin wetlands, riparian areas, and gullies, and/or terrace slopes. The greatest opportunities for biodiversity enhancement may be as larger stepping-stones that have reduced 'edge habitat' and extend further from the road, rather than road corridors that are very edge-dominated, vulnerable to weeds, and likely to be used by predators such as rats, cats and possums to move through open landscapes. Changing management of land adjacent to the SH73 corridor also impacted the road edge-effects. For example, intensification of farmland over time has removed connectivity and increased the value of the state highway as biodiversity nodes. In contrast, removal of Russell lupin, pines and other weeds in adjacent lands means those weeds remaining in the state highway margin represent a greater threat to adjacent ecosystems.

The way the road is managed also influenced the extent of road edge-effects. In this case study, negative road edge-effect pressures were exacerbated by:

- spread of some pest plants along and within the road corridor that were largely absent from the adjacent landscape, such as hawthorn, apples and stonefruit (spread by road users); in places, broom; and in one rest area, landscaping with the pest tree silver birch
- extensive use of herbicide around marker posts and culverts creating bare ground vulnerable to establishment of non-native plants that are uncommon in the adjacent landscape
- large construction/infrastructure sites that were unrehabilitated, contained weed species, were used for casual public access and dumping of rubbish, and accentuated fragmentation
- browsing by hares in areas planted with palatable native plants (eg, *Coprosma acerosa*); it is very difficult to control hares on roadsides.

Some road edge-effects were unable to be adequately assessed. Determining the impact of light and road noise was problematic given the paucity of New Zealand data on levels and frequencies that create adverse effects on indigenous species that were present; however, an important action to reduce road edge-effects in all future SH73 capital projects is to stop adding more artificial light and use 'quiet' road surfaces. A similar lack of information occurs for roadkill and for impacts of road noise on bird population densities (and consequent population-level effects). The size of the 'road-effect zone' created by light, noise and roadkill for all native terrestrial animals in the SH73 case study was therefore a guess.

5 Recommendations and conclusions

5.1 Introduction and overview

This project was funded to help Waka Kotahi identify, assess, monitor and manage road edge-effects on biodiversity associated with new and existing roads. This report addresses effects of roads that are measured from the road surface into the adjacent edges: noise and vibration, artificial light at night (ALAN), stormwater runoff, air emissions, hydrological effects, habitat modification, and impacts of road users (people), as well as roadkill and land fragmentation. The two latter effects are primarily caused by a road's physical footprint and traffic along roads, but roadkill interacts with adjacent populations, so it generates effects that can be measured away from roads, and fragmentation effects are also impacted by road edge treatments during construction and maintenance. Hence both roadkill and fragmentation are included in this project as road edge-effects. All the effects are amplified or moderated by road and vehicle typology, landscape characteristics, and the characteristics of the ecosystems and species within the zone of influence of the road.

'Significant ecological effects' cause changes in population or community structure that are significantly different from areas that do not have roads (Forman et al., 2003). Ecological impact assessments of Waka Kotahi projects provide an early indication of ecological risk and opportunities during project development, and later to support the assessment of effects on the environment as part of the project consenting process. However, there are very few New Zealand data available with which to assess the type and level of most effects and whether additional management is required. Effects also change over time: during construction, physical edge effects are more sharply delineated, and noise, light and stormwater effects are also markedly different from those generated by road networks with operational traffic. The magnitude of an effect on biodiversity can also change with changes in adjacent landscape management. This project reviews international literature on road edge-effects and relevance to typical New Zealand highways and New Zealand terrestrial ecology, using wetlands as an example where the interface between water and land are explored.

5.1.1 Literature review

A literature review (summarised in section 5.2) identified road edge-effects and classified them. In this project we included all impacts of roads on biodiversity as road edge-effects because (a) they are measured to some degree away from the road surface and (b) a 'road' itself can be defined as the running surface and the intensively managed margins or 'road envelope', which is trafficked less frequently to control vegetation and drainage, as well as wider area directly impacted during construction. Road edge-effects are traditionally more narrowly defined as 'the area over which significant ecological effects extend from roads' (Forman & Deblinger, 2000), which excludes roadkill and fragmentation. However, the infographic 'How highways impact conservation areas' (Figure A.7 in Appendix A) shows how fragmentation (driving animals to enter road corridors) and roadkill (unsuccessful crossing of roads) are inextricably linked with other road edge-effects on fauna.

The size of the road envelope varies with road typology – for example, decreasing from motorway to state highway to arterial road and local road, but often extends to roadside drains or water tables, hence the severity of effects such as fragmentation are impacted by the road envelope and its management. Particular emphasis was placed on effects likely to be influenced by New Zealand's unique ecology. This was aided by engaging New Zealand researchers with expertise in native forest birds, pest mammals, pest plants and restoration ecology. Researchers reviewed international and national literature on road edge-effects, then assessed which edge effects 'matter' in the New Zealand context. Measures of the key road edge-effects are proposed. Researchers also identified actions and opportunities to enhance positive effects and/or avoid or mitigate negative road edge-effects. Because data on the significance of ecological effects on many New Zealand ecosystems and species are severely limited, we used a precautionary approach that identified a wide range of potential effects and the features that were considered likely to moderate or amplify them.

5.1.2 National database interrogation

Alongside the literature review, national databases were analysed to identify threatened ecosystems, natural areas, New Zealand highways, and road characteristics in each region, and where the effects of roads were considered likely to be most positive or negative. National databases enhance consistency across regions. These include an updated national layer of Protected Areas Network – New Zealand (PAN-NZ) data. This layer was useful because the impact of road edge-effects on biodiversity values is strongly influenced by the sensitivity of adjacent environments. The PAN-NZ layer identifies areas primarily managed for conservation by the Crown (through DOC), by territorial authorities (eg, parks, reserves) or by individuals through legal conservation covenants. PAN-NZ data were combined with national Land Cover Database (LCDB) data to identify wetlands and dominant vegetation at the 0.5–1 ha scale. The Threatened Environments Classification (TEC) database was used to identify where small, degraded remnants and regenerating ecosystems are likely to have disproportionate ecological value because they are 'all that is left'. Road edge pressures were derived from LINZ and Waka Kotahi data on vehicle numbers, noise contours, and locations of streetlights, bridges and culverts. National maps were then generated to show where highways intersect sensitive areas on a national scale. The tabulated results are summarised in the following infographics in Appendix A:

- Highway traffic volumes and road density are unevenly distributed (Figure A.1)
- Highway verges may act as refuges in depauperate landscapes (Figure A.2)
- Highways impact conservation areas (Figure A.3)
- Sensitive sites: where highways with lighting intersect with wetlands, coasts, and conservation areas (Figure A.4)
- Vehicles as predators of native birds: Impacts and contributing factors (Figure A.5)
- Vehicles as predators of native birds: Mitigation (Figure A.6)
- How highways impact conservation areas (Figure A.7)

5.1.3 A method to assess edge-effects

We developed a method for assessing edge effects (section 2) using data sources available in New Zealand. This four-step process began with a desktop analysis using outputs from the national databases (above) supplemented with regional information and a rapid field assessment. We tested the road edge-effects assessment method on two contrasting case studies (SH16/18 and SH73) with sections of recent capital projects.

The SH16/18 case study includes largely dual-lane, separated highways with treatment of road runoff in wetlands and extensive buffer plantings of native species. These state highways carry 30,000–60,000 vehicles/day through biodiversity-depauperate, urbanising outskirts of Auckland's north-west, as described in section 3. The second case study looked at sections of the Great Alpine Highway (SH73) in the Waimakariri Basin. This narrow, single-lane highway has no formal stormwater treatment. It carries up to about 5,000 vehicles/day through locally depauperate agricultural landscape and high biodiversity-value conservation lands that include Arthur's Pass National Park, as described in section 4.

These case studies showed that while general road edge pressures and pressure points can be mapped using national and regional data, field assessments are needed to identify edge effects caused by pressures from pest plants/weeds and roadside maintenance effects, including those on stormwater runoff quality. Field assessment was also needed to confirm potential values of small areas in depauperate landscapes that had the potential to act as biodiversity nodes or corridors. The case studies also illustrated the greater edge effects of new roads (5–15 years old) compared with old roads. Greater effects result from more extensive cut and fills, and greater impervious areas, which together impact soils, hydrology, and stormwater runoff. In the Arthur's Pass study, edge effects were exacerbated by reduced habitat quality within earthworked and rehabilitated areas caused by competition from non-native plants/weeds. However, both case studies illustrate the potential of road corridors to enhance biodiversity in farmed areas where a low proportion of native ecosystems remain. In this context, it is important to anticipate how changes in adjacent land management influence the likelihood, extent and reversibility of edge effects. Because road corridors are narrow, the way adjacent land managers control vegetation can strongly influence weed, light and noise pressures, and the presence of native plant and animal populations. Local pest animal pressures were also influenced by adjacent land management. For example, where populations of vulnerable species such as kiwi and kea are enhanced, roadkill may also increase unless mitigated, and where populations of pest pines were removed from adjacent land, pines remaining within the road corridor contribute more to adverse effects in the landscape.

5.1.4 Recommendations

The literature review and the findings of the case studies were used to develop a list of recommendations for future identification and management of edge effects from roads (section 5.3). These include using the road edge-effects assessment method at an early stage in route selections for capital projects as a strategy to avoid effects on high-value biodiversity likely to be adversely affected by road edge-effects – for example, not severing wetlands or remnants in depauperate areas, and not having road lighting in 'dark' areas. The road edge-effects assessment method also helps identify depauperate areas where road corridors could enhance biodiversity. Such enhancement increases 'core' areas of remnant ecosystems by using buffers to reduce disturbance, noise and light effects. The road edge-effects assessment method emphasises road design and maintenance that reduces permanent, cumulative road edge-effects linked to regular disturbance that exposes sites to erosion and weed establishment, stormwater runoff and its contaminants, and the impacts of pest plants (especially outlier and 'sleeper' weeds that are not yet problems). Final recommendations include long-term investment to limit the spread and impacts of weeds, and research to assess the effectiveness of investments in avoidance and mitigation, especially for capital-intensive investments required to reduce road excavation footprints, enhance runoff treatment, and retain land for biodiversity in depauperate areas.

5.2 Summary of literature review

The literature review consistently showed that road edge-effects are generally negative. The effects of noise, light, stormwater runoff containing contaminants, roadkill, and the creation of 'edge ecosystems' that tolerate high exposure and/or disturbance associated with maintenance are ubiquitous. Such edge ecosystems are very different from the humid, shaded, native forest 'core' that dominated New Zealand before deforestation, and to which many forest-dwelling native invertebrates and plants are adapted. These effects are permanent unless deliberately managed. Some road edge-effects increase with increasing traffic density (eg, noise, contaminants and, to a point, roadkill). Other effects increase with road footprint and the addition of specific infrastructure such as streetlights, bridges, drains and unbuffered stormwater discharges. The magnitude and extent of impacts differ depending on species and ecosystems present in the wider landscape, and the characteristics of the landscape, notably the extent to which roadside habitat is present in the wider landscape. The effects, and potential presence of thresholds at which mitigation is required to manage a moderate level of adverse road edge-effects, are not known for most ecosystems or most individual native species. Exceptions are where light impacts bats or seabirds, stormwater discharges to wetlands, and where the edge habitat does not support specific species. Road edge-effects are most likely to be positive in depauperate landscapes where road corridors increase core area of habitat or potentially create or contribute to corridors, provide a source of native propagules that can spread into adjacent landscapes, or provide barriers to the spread of non-native weeds or pests. But such positive effects are more likely with active management to limit both weeds and pest animals.

Roads have to efficiently and safely transport vehicles, but many New Zealand roads can also be significantly and measurably better at reducing harm to native biodiversity, and in some places, enhancing native biodiversity. The following section identifies actions to achieve these outcomes. A range of effects management strategies are available to reduce harm associated with new and existing road assets. The importance of such interventions is likely to increase in the future, as the number and/or extent of roads increases and the edge effects of existing roads increase over time, especially those negative, cumulative effects linked to traffic density, lighting, stormwater contamination, vegetation maintenance linked to agrichemicals, and the spread of weeds. Native roadkill may increase if Predator Free 2050 increases populations of vulnerable species, and/or if further intensification of areas adjacent to roads reduces alternative habitat – but what matters is effects at a population level. Grey literature indicates management practices are available to mitigate roadkill of some species. The adverse effects of new and ‘upgraded’ roads are also likely to increase where these projects increase the impervious surface area, the width and/or extent of cuts, and fill slopes (to increase traffic speeds, meet new design criteria, and install safety barriers). Where road edge-effects are positive, there is likely potential to further enhance effects, particularly by increasing buffering of remnant habitat. In rural and urban areas such buffering and use of stormwater mitigation with planted (green) infrastructure can also deliver valued co-benefits such as enhancing human wellbeing and productivity of agricultural areas.

5.3 Recommendations

The following recommendations improve measurement and reporting of road edge-effects (section 5.3.1, summarised in Table 5.1 and Table 5.2), increase use of methods to mitigate or enhance road edge-effects on native biodiversity (section 5.3.2, summarised in Table 5.3 and Table 5.4), and underpin these methods with increased certainty on their efficacy (section 5.3.3). Some effects management strategies require construction and maintenance of assets, and this requires knowing where assets are. Conventional assets, such as culverts, pipes and streetlights, are recorded in the RAMM database; however, the RAMM database does not appear to consistently record green infrastructure (stormwater ponds, wetlands) or fish passage, and no records of wildlife underpasses or exclusion fences were found.

Key objectives in this study are to enable identification of beneficial effects of roads on biodiversity that could be expanded, and adverse effects that can be reduced. Prioritised adverse effects include cumulative and permanent effects resulting from the fragmentation and reduction of habitat quality that reduce species productivity. Such effects can occur from road-derived noise or lighting, biophysical changes induced by weeds, hydrological change or exposure, or landscape-level changes due to fragmentation.

Recommendations are presented in three sections. The first discusses the approach to measure and quantify road edge-effects that was developed and tested in two case studies within this project and proposes 12 indicators for measuring and reporting road edge-effects on biodiversity (section 5.3.1). The second section tabulates actions that can reduce adverse road edge-effects, using the categories adopted in the road edge-effects assessment method (section 5.3.2). Actions that can promote positive outcomes linked to roads are also included in this section. The final section recommends research, monitoring and evaluation to improve certainty related to specific road edge-effects (section 5.3.3), and includes reporting of roadkill, agrichemical use and weeds, research by management on effectiveness of buffers, and fundamental research – for example, using ‘ghost roads’ to determine effects of noise and light on native birds, lizards and invertebrates.

5.3.1 Road edge-effect method and indicators

Better monitoring and reporting of road edge-effects on native biodiversity is needed to underpin business cases for investments to improve performance of New Zealand roads for biodiversity. At present there are insufficient data to underpin investment decisions. We identified 10 indicators that cover the range of road edge-effects identified in the literature, which we then applied in the road edge-effects assessment method (section 2) and case studies. Some measures are suitable for existing highways at a national scale (Table 5.1). Other measures would be practical to apply only to capital projects (ie, new builds and road upgrades such as realignments and safety improvements) and could be reported at project planning and completion (Table 5.2). Most indicators need further development and testing. Where possible, a weighting that considers biodiversity value and magnitude was built into the indicator. In many cases the value of a biodiversity component is indicated by the TEC, the New Zealand Threat Classification System (for individual species), the age of structural components, and whether or not the road is adjacent to a sensitive biodiversity area or depauperate area. This approach was used in the road edge-effects assessment method (section 2), but for capital projects, explicit consideration of the age of structural components (ie, trees) is a surrogate for irreplaceability, although a specific measure for wetlands would also be useful.

Table 5.1 Proposed indicators of road edge-effects on biodiversity

Indicator category	Description	Comment
Noise	Modelled noise above 55 dB $L_{Aeq(24)}$[93] overlapping natural ecosystems	This coarse measure reflects the absence of data on responses to (traffic) noise for New Zealand species, and current Waka Kotahi-modelled noise maps that have a lowest threshold of 55 dB. This is a placeholder until data are available.
Artificial light	• Kilometres of sensitive areas with conventional streetlights • Kilometres of sensitive areas with light mitigation	A placeholder until recommendations of a Waka Kotahi research project on lighting are available. Measures are likely to be species-specific. Sensitive areas would include habitats of vulnerable, threatened species.
Stormwater	Extent/size of high-contaminant-generating surfaces and degree to which runoff is mitigated by treatment devices where stormwater is not directly discharged to surface waters.	Explore weighting by sensitivity of receiving environment as these have been mapped. Define 'treatment device' to consider level of mitigation (eg, catch pit has low efficacy compared to a bioswale). Define the flow path distance that equates to 'not directly' discharged. Could consider adding m^2 of impervious surface; however, a more direct measure could be linked to network outcomes contract maintenance surveys of outlets where these consistently include a measure of 'scour' (erosion).
Fragmentation	Area of core vegetation not influenced by road edge-effects within 100 m of road centreline[94] (landscape level)	This aims to encourage defragmentation and buffering and discourage new roads through key habitats. It could be weighted by the TEC, and allow for non-native nurse crops. Decide how to treat wetlands, including stormwater treatment wetlands.
Fragmentation and biophysical edge effects	Linear kilometres of highway with > 50 m tree gap where forest or shrubland is on both sides of the road	Limited data indicate ~50 m edge effect and smallest birds cannot cross 110 m deforested gap. A better alternative may be a multiple of adjacent tree or shrub height, as edge effect generally decreases with canopy height. This could be generated from Lidar in future. This underestimates effects on some native invertebrates for which any road would be an impassable barrier.

93 $L_{Aeq(24)}$ is time-averaged A-weighted sound pressure level over 24 hours, measured in dB (decibels, the unit of sound).

94 Road centreline is used because it can be mapped consistently; however, a better ecological measure may be distance from the edge of the impervious surface because this considers road width.

Indicator category	Description	Comment
Weed species*	Ecological weed/pest plant species on roadsides that are not on adjacent land	This could be restricted to roadsides within a specified distance of ecosystems with high ecological values. It would be reported by network outcomes contractor by region and for specific capital projects. This measure requires a baseline as these data are not currently recorded. Ecological weed species are a long list that includes 'sleeper' weeds, not just plants on regional council pest management strategy lists.
Weed buffers*	Area with high ecological value within 500 m of road protected by weed/pest plant buffers maintained to protect ecological values	This requires weed control and preferably rehabilitation or other practices required to limit weed re-establishment and could be effective where jointly done with local NGOs and DOC to deliver outcomes (eg, Arthur's Pass).

* indicates measures only in areas with high ecological values and their buffers

Table 5.2 Proposed indicators of road edge-effects on biodiversity used for capital projects, in addition to the indicators in Table 5.1

Indicator category	Description	Comment
Critical ecological features	Key ecological features maintained in high value ecological areas and rehabilitated areas to a condition at which they are effective	Critical features include flight paths, roosts (logs, log piles, shell banks, stone piles) and nest boxes/cavities. Could include specific plant species or ground cover. These need to be field-checked and may be linked to resource consents.
Roadkill	Number of projects meeting annual roadkill reduction targets	Projects include crossing structures such as bridges or culverts, exclusion fences, but not conventional signs. Reduction targets require before and after monitoring, or concurrent 'control' areas. A complementary measure may be assessed condition of structures (Warrant of Fitness). The value of conservation outcome could be included by weighting for species. Data may be collected by volunteers/NGO/DOC but need collaboration with network outcomes contractors to ensure safety.
Ecosystem degradation	• Area of cleared vegetation and soil excluding impervious surfaces within road corridor • Area of rehabilitated vegetation within road corridor achieving canopy closure or rehabilitated state	This targets capital projects. Together the measures provide balance of 'habitat' delivered by a project. This needs to be heavily weighted by TEC and have time to develop pre-disturbance habitat structure so as to not encourage substitution of old, threatened, complex ecosystems with young, common, simple ecosystems (such as rehabilitated planting or regeneration).

The 'weed species' and 'weed buffers' indicators are included to help overcome the strong bias towards acting too narrowly and too slowly to prevent weeds degrading natural environments, issues highlighted by Hulme (2020). Weed control typically acts too narrowly by:

- targeting too few species
- not including all ecological threatening weeds
- not identifying or removing first occurrences and the expanding 'front' of weeds
- not treating areas where weeds are removed to prevent re-invasion – for example, by rehabilitating to a condition that prevents re-invasion.

The future biodiversity liability incurred by new weeds establishing into areas of high ecological value is likely substantial, even though research indicates a very small proportion of weeds are spread along New Zealand roadsides.

5.3.2 Recommended methods for managing adverse edge effects and enhancing positive road edge-effects

A wide range of methods are available to avoid and/or mitigate negative road edge-effects on biodiversity and enhance positive road edge-effects within the road corridor; however, there are few data on the efficacy of many methods. The effects management hierarchy requires a project to (first) avoid, (second) minimise, and (third) mitigate negative effects, followed by opportunities to enhance positive effects. Effects management is not solely a design issue actioned during project planning; the effective implementation needs to be verified during construction, and maintenance must ensure ongoing performance.

Van der Ree et al. (2015) outline the steps required for effective mitigation of road effects. First, the effects to be mitigated need to be identified. Second, mitigation options with specified design intentions and success criteria need to be developed alongside likely options for adaptive management. Mitigation options must be feasible, able to be specified in contract documentation, and able to be constructed with the equipment available. Key components must be retained through project ‘value engineering’. If projects involve salvage and re-use of materials from the stripped footprint, or work before stripping, or treatment of adjacent or upstream areas (eg, to retain habitat or habitat features), this needs to be included in relevant sub-contractors’ contracts (eg, vegetation, earthworks contractors). The areas need to be able to be monitored during construction, and when the road is ‘live’. This means ensuring safe access, which may need to be specifically designed into the project. Third, identify what maintenance is needed, how and who will do the maintenance, and where the funding will come from. Consider how other road maintenance actions may impact the mitigation (eg, mowing, herbicide application, water-table treatments), especially where these are carried out by different contractors who may have different priorities and key performance indicators. In cases where mitigation strategies are unproven, or linked to resource consent requirements, the efficacy of installed mitigation measures should be tested. This may require pre-construction monitoring at control and mitigation sites, supported with ongoing monitoring to ensure design components are retained through the life of the intervention. Monitoring should inform adaptive management.

Some forms of effects management have been highly effective at reducing the disturbed footprint of Waka Kotahi projects. These range from tunnels and bridges to retaining walls and tree-cabling to retain undisturbed habitat, reduce clearance widths, and reduce damage to key ecological structures (eg, floodplains). Specific examples include retrofitting green infrastructure to treat stormwater runoff from high-contaminant-generating motorways and highways in Auckland (case study, section 3). The 7-monthly weed surveys of road verges in Waipoua Forest, in which new weeds are identified, marked, and killed or removed before they can fruit, are also effective (but costly given traffic controls). Restoration of closed roads to reconnect previously fragmented forest and shrubland ecosystems in Arthur’s Pass (case study, section 4) is also a mitigation strategy that could be more widely applied. Early monitoring indicated artificial habitats for translocated peripatus within pine forest at Dunedin were successful, as was establishment of new populations of *Coprosma acerosa* at Mingha Bluff, Arthur’s Pass (case study, section 4).

In the absence of information on most road edge-effects on native species (including thresholds that indicate at what level adverse effects occur), the value case for construction of capital-intensive mitigation can be difficult to justify. However, in some cases, low-cost precautionary actions can be adopted in road design and maintenance. Application of such actions should focus on areas with high ecological values, and where the cost of remediation or retrofit is likely to be high. For example, replacing existing road lighting with alternatives that allow efficient manipulation of light intensity and duration is a low-cost, precautionary approach. Another example is not allowing weeds to establish in parts of road corridors where they are absent in general, particularly within 'striking distance' of high-value natural areas. The steady increase in weed diversity and density across natural areas of New Zealand cannot be halted without such Waka Kotahi input, particularly since working in the road corridor requires stringent health and safety assessments, which will often mean traffic controls are required to do such necessary biodiversity work.

Potential mitigation actions are listed in Table 5.3 and Table 5.4. These tables group effects management measures into the seven edge-effect impacts presented in the literature review (section 1) and used in the proposed road edge-effects assessment checklist of impacts (section 2). Offsetting or compensation is not covered in the table, although actions that enhance environments may also be used in both. Key effects management strategies include the following.

- Avoid new roads in areas where adjacent land is managed for conservation and other sensitive ecological environments. Where additional roading is required in such areas it may be preferable to widen existing roads (noting that this could exacerbate existing effects, particularly on sedentary or less mobile species).
- Avoid bisecting, impeding, or draining wetlands. Avoid habitat remnants in depauperate areas and habitats of species that move short distances from the coast inland to breed, moult or rest (eg, estuarine birds, penguins, seals).[95]
- Avoid building infrastructure support areas (eg, gravel stockpiles, turn-arounds) in fragments of habitat in landscapes where habitat is already scarce, and in continuous areas of core habitat (put them adjacent to farmland).
- Do not add new road lighting in areas where artificial light is currently absent,[96] particularly in areas with potential conservation or ecological values and/or particularly over water (bridges). Avoid new lighting assets within habitats or flight paths of vulnerable species (some evidence is available for seabirds and bats).
- Avoid direct stormwater discharges to surface waters by using permeable road shoulders.
- Do not apply herbicides in areas with sensitive receiving environments. This can be achieved by:
  - designing water tables as mown swales that do not need herbicide application rather than drains
  - replacing edge marker posts with on-road delineation.
- Do not introduce or facilitate spread of weeds in general, and specifically within sensitive ecological areas. This can be achieved by:
  - using road design that considers access for safe maintenance/surveillance
  - maintaining fully vegetated edges (without bare areas)
  - selecting and specifying revegetation plants to avoid non-local species
  - avoiding creating areas maintained by routine broad-spectrum spraying, and establishing buffers to reduce weeds moving into the road corridor from weedy adjacent areas and along road corridors.

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[95] Some national policy statements require avoidance strategies to be implemented, eg,eg, the New Zealand Coastal Policy Statement 2010 for visual impacts in sensitive areas (policies 6 and 15), reclamation (policy 10) and threatened or at risk native biodiversity (policy 11). The National Policy Statement for Freshwater Management 2020 requires no reduction in the extent of wetlands and avoidance of effects that would adversely affect wetland habitats. Others may be required under the future National Policy Statement for Indigenous Biodiversity, particularly for ecosystems that cannot be rehabilitated within ~25 years.

[96] See Australian Government Department of the Environment and Energy (2020). *National Light Pollution Guidelines for Wildlife.* https://www.awe.gov.au/sites/default/files/documents/national-light-pollution-guidelines-wildlife.pdf

- Use ‘quiet’ road surfaces in sensitive areas and/or lower the speed limit in highly sensitive areas (especially where threatened native species are vulnerable to roadkill). Consider impact of low speeds on noise created by electric vehicles. Ensure bridge designs reduce sudden ‘fright’ noises when vehicles cross, and designs reduce noise amplification under bridges. Reinforce speed limits with ‘slow’ road design (eg, sightlines).

Table 5.3 Potential mitigation actions for capital projects to decrease severity, duration or scale of adverse road edge-effects, including roadkill and fragmentation. Actions likely to enhance biodiversity values are italicised.

Edge-effect class and contributing feature	Actions to decrease the severity, duration or scale of the adverse effect *or to create benefits*
Noise and vibration	
Noise generation: road design	Use low-noise-generating road surfaces. Incise roads to reduce ‘uphill’ noise spread, especially where noise will otherwise spread across open landscapes and/or water.
Noise generation loud areas	Locate ‘loud’ road features (tight corners, steep grades) in areas with high background noise (urban) or white noise (surf, river rapids, windy sites with plants that create white noise, such as flax, toetoe and some (evergreen) trees).
Noise severity	Use low-noise-generating road surfaces. Incise roads to reduce ‘uphill’ noise spread, especially where noise will otherwise spread across open landscapes and/or water.
Light	
Light presence	*Remove existing lighting in high ecological value areas where it is not really needed.*
Light presence	Use alternative methods of road delineation to achieve safety requirements, rather than streetlights.
Light spread	Incise road in sensitive areas or use cut/fill with bund on the fill slope. Do not elevate roads in sensitive areas.
Light spread	Shield road lights and use barriers to block headlight spread, especially at corners where light travels a long distance. Barriers can include plants (when dense and tall enough).
Light frequency/colour	Use frequency, colour/wavelength and flicker that does not impact target species (noting data are limited, even for seabirds).
Light duration	Design lights that can be programmed to control light intensity, brightness and duration (eg, turning off during petrel maiden flight period).
Background light	Work with owners of adjacent land to mitigate adverse effects of light, especially in areas with low background light (this could include reducing lights on their properties as well as along roads).
Stormwater runoff	
Runoff volume generated	Minimise road width/impervious surface area to reduce volume of runoff. Ensure road shoulders are permeable to reduce and slow runoff.
Runoff volume delivered	Treat earthworked areas, cuts and fills to enable infiltration and reduce runoff (eg, create rough surfaces, create permeable surfaces protected by leaf litter or mulch layers and dense vegetation cover, create deep root zones by ripping where geotechnically feasible and deepening topsoil). Separately strip and replace topsoil(s) and, where suitable, amend with additional organic matter to increase moisture-holding capacity and permeability.
Runoff volume attenuated	Use detention devices (including wetlands, infiltrating swales and basins, and raingardens) to reduce discharged volume, peak flow, and contaminant loads (catchpits are not as effective, unless fitted with gross pollutant traps and adequately maintained).
Runoff contamination (agrichemicals, disease)	*Design to avoid use of agrichemicals in areas where runoff could enter natural wetlands or surface waters* (eg, use mown batters and vegetated swales). Design to reduce movement of soil into water tables when in areas with kauri dieback).

Edge-effect class and contributing feature	Actions to decrease the severity, duration or scale of the adverse effect *or to create benefits*
Runoff peak flow	Minimise direct connections (catchpit to pipe to stream). *Set back discharge points from streams to allow cooling, treatment and disperse runoff over large area to reduce point erosion in receiving waters.*
Runoff contamination (zinc, spills, sediment)	Use low-friction surfaces to reduce tyre wear (zinc and microplastic generation). Gentle grade and corners reduce braking (copper), tyre wear and spillages, especially where roads service industrial areas/quarries and truck movements are high.
Runoff attenuation	*Filter road runoff and cut-off drain runoff through plants and soil (swale or verge) close to source (occurs on many rural roads/old highways without kerb and channel).*
Hydrology	
Effect on groundwater	Minimise cut/fill that exceeds depth of root zone, intersects groundwater, or blocks surface water flows. *Facilitate infiltration into soil and underlying subsoils of non-contaminated stormwater runoff where this is similar to adjacent ground.*
Effect on water table in root zone	Select cut/fill slopes, cut-off drains, and replaced soil drainage profiles that have 'draw-down' zones similar to those in adjacent undisturbed ground. Wetlands and ecosystems with perched water tables are highly vulnerable.
Effects on wetlands	Adopt the setback zones for wetlands prescribed in the National Environmental Standards for Freshwater. Small hydrological changes can drive changes in composition and habitat provision.
Effect on adjacent vegetation	Do not undertake earthworks or stormwater discharges that impact the drip zone of old trees or drought-tolerant herb fields. Target young vegetation with wide drainage tolerances (eg, mānuka).
Effect on drought tolerance	• Match hydrology and water-storage volumes in root zone of restored buffer areas to match the duration and frequency of drought/anaerobic conditions in area buffered. • Develop replaced root zones that consider effects of aspect. South and east are more shaded with lower water losses (higher moisture, less water stress); north and west slopes are likely to experience greater water stress.
Effects on groundwater	Consider impacts of adjacent land-users on hydrology and water quality, especially if intensively drained, irrigated or being intensified in a way that will impact stormwater runoff (eg, removal of headwaters with urban expansion; forest conversion to pasture).
Stream flows	Ensure road runoff complements the area, depth, duration and/or frequency of flood/inundation of adjacent waterways. This may be aided by reducing the area of catchment that reports to individual culverts or discharge points and focusing on detaining water high up in sub-catchments where detention has the greatest impact on flows.
Habitat modification, landscape effects, fragmentation	
Fragmentation of remnant habitats/ ecosystems	*Reconnect remnants. In some cases, reconnection requires enhancement of specific pollinators and propagule spreaders. Note, however, that reconnection is not always beneficial, as it may allow access by predators (eg, trout or mammals) and may encourage dispersal to 'unsafe' areas (eg, native birds that are highly vulnerable to predation moving out from predator-controlled areas).*
Fragmentation of native animal populations	• *Develop reconnection strategies to overcome features that create barriers for species of concern – for example, robins and other insectivores can use older forest plantations and may fly gaps less than ~110 m. Design bridges/culverts to allow passage of animals and plants as well as fish. Note potential dangers of reconnection identified above.* • *Increase size of fragmented remnants by buffering so they become more effective stepping-stones (potentially for a wider range of species), or adding habitat features that are missing from degraded or immature habitat (see 'Enriched ecological features' below).*
Barriers created by absence of trees	Maintain continuous edges where flight paths cross roads. *Reduce tree gaps at potential crossing sites by retaining 'outlier trees' that are protected from adverse hydrological changes*, translocating trees into edges (for tolerant species) and, as a last resort (due to the delay in delivery), plant new trees into amended root zones that will support the target mature and stable tree canopy.

Edge-effect class and contributing feature	Actions to decrease the severity, duration or scale of the adverse effect *or to create benefits*
Barriers created by ongoing disturbance	• Design roads to minimise the area, length, and continuity of mown or pruned roadside strip. • *Design roads to minimise areas of bare ground, especially areas regularly sprayed with herbicide*.
Barriers created by adverse microclimates	• Address light, heat and moisture microclimate effects within wider road corridor as well as vegetation characteristics and gaps. Improve the capacity of concrete structures to support mosses, ferns and epiphytes by adapting surface texture (eg, so aesthetic patterns are ecologically functional). This has been done for sea walls, where surfaces are created with microclimates that encourage colonisation by sea life. Bridges that create rain-shadows should direct stormwater runoff into pockets within dry areas to create favourable microclimates for plant growth. • *Create favourable microclimates and habitats for identified components of ecosystems that require coarse wood, rock refuges and translocated soils/leaf litter layers (eg, soil invertebrates, some lizards*). • *Develop edge-specialist plant communities that create multi-layered, dense edges that do not need regular pruning, and therefore more effectively buffer adjacent ecosystems*.
Increased 'safe' road corridor 'edge' habitat	Check road edge habitat does not increase risk of death from roadkill or predation by domestic pets using roadside walking tracks; this has been observed anecdotally in farmed landscapes where animals seek dense cover (weka, kiwi) or where food resources are created near live traffic lanes (tree lucerne for kererū). Where habitat can cause ecological traps, exclusion fencing may be needed to reduce access, or habitat removal with more habitat created in safer areas.
Ecotones	*Conserve, enrich and create ecotones within road corridor using stormwater/flood management areas (eg, replacing ditches with vegetated swales that have variable widths; disrupting smooth, even, homogenous cut or fill faces to integrate edge-habitats*).
Increased native seed sources	*Enhance native seed sources in depauperate landscapes where the road corridor contains suitable species, pollinators and spreading agents (eg, birds). This usually requires some pest plant control and favourable vegetation control regimes such as selective herbicides or higher mowing, or timing mowing for immediately before an annual growth flush (eg, kiokio fern) or after seed matures (eg, orchids, some native herbs).*
Enriched ecological features	*Identify opportunities to enrich areas that could be habitat for target native species, especially immature planted or regenerating areas that have simple structures and could be expected to mature to have complex structures.* Critical features include roosts (log piles, shell banks, stone piles), standing dead wood and nest boxes/cavities. Critical features also include specific plant species that provide food in winter, or are needed for invertebrates to complete their life-cycle, such as nettles for admiral butterflies. Critical features in degraded forests include specific structural layers such as dense, connected shrub or subcanopy layers, epiphytes and lianes, or deep leaf-litter layers.
Enriched remnant habitats	*Sustain effective pest plant control. Reduce accumulation of contaminants derived from road stormwater runoff* (eg, capturing, filtering and reducing peak flows that otherwise degrade wetlands or surface waters).
Reduced browse of native plants by pests	Reduce access of mammalian browsers to the road corridor, facilitate control of pest animals, use establishment techniques that overcome browsing (eg, plant sleeves to protect against hares and rabbits).
Disturbance at critical times	Capital projects should time vegetation clearance and earthworks to minimise impact on species that use specific areas seasonally (eg, nesting, breeding, or moulting seasons, feeding seasons of migratory shorebirds). Time clearance and exposure of bare soil to maximise natural regeneration where suitable native plants are nearby (this is most effective when it is asynchronous with seeding of weeds).
Establishment of pest or weed plants in road corridor	In natural environments, do not hydroseed with non-native nitrogen-fixing species, and do not add phosphorus fertilisers to hydroseed mix. Do not landscape with 'weedy' species. Manage earthworks to isolate and prevent spread of long-lived seed banks (gorse, broom, some *Juncus*).

Edge-effect class and contributing feature	**Actions to decrease the severity, duration or scale of the adverse effect *or to create benefits***
Spread of pest plants to natural areas	During project construction, ensure weed sources in adjacent areas are eliminated and/or buffered to minimise establishment of unwanted species into the project footprint. Priority areas are above or downstream of places that are both vulnerable (eg, low vegetation cover) and difficult to access (eg, due to gorse, broom or acacia above tall cut batters). Such weed removal and buffers should be established before disturbance occurs. Buffers are usually dense areas of target (native) plants, and ideally include species that will seed or spread into adjacent disturbed areas.
Roads used as corridors for non-native predators	Predict when road edges may enable movement of mammal predators (eg, road edge woody vegetation in depauperate areas and roads through wetlands). Where predators are not present (ie, being controlled in adjacent landscape) consider creating areas for trapping that are serviceable from the road.
Road users/road neighbours	
Neighbours of protected areas assist conservation outcomes	Collaborate with managers of neighbouring land managed for conservation/native biodiversity by enabling effective predator and/or weed control and by buffering adjacent vegetation.
Cumulative effects from linear infrastructure	Identify where railway or transmission lines, water races or drainage schemes align or cross a road corridor, particularly where the combined corridor is much wider or connects ecosystems. Assess opportunities to achieve greater biodiversity benefits, especially in depauperate landscapes. Assess risks where habitat gaps and weeds are exacerbated.
Neighbour verge management	During road design, consider whether the impact of verges managed by neighbouring owners using mowing, herbicide, drain clearance, shelter-belt management and landscaping practices are hostile or complementary to native biodiversity objectives for the road corridor.
Gross pollutants (litter, plastics, lead weights)	Identify roadsides with high gross pollutants and/or vulnerable receiving environments (eg, high traffic flows near estuaries, coasts or bridges within ~15 minutes' drive of fast-food outlets, pullover areas and rest areas near towns), and mitigate (eg, by using gross pollutant traps).
Habitat disturbance from access to edges	• Ensure road shoulders are too narrow to allow vehicle stopping in sensitive areas. • Define roadways at rest areas. • Use informative signs at pullovers with access to waterways, coastal areas, vulnerable alpine environments, sites with views (especially those where people may access beaches/river flats with nesting birds, and where they may remove or transport 'pretty' weeds such as Russell lupin, agapanthus and pampas).
Roadkill	
Roadkill – non-native animals	• If roadkill is locally concentrated (eg, bridges), consider methods of enhancing kill rates of non-native mammals with trapping, and ensure safe access and parking areas for people servicing the traps. • If roads are adjacent to predator-control zones, consider how roads can be designed to be a barrier to mammal re-invasion. There are likely to be weak points (eg, culverts for rats) and bottlenecks that are defined by topography, vegetation patterns, bridges, or noise walls.
Roadkill – native animals	• *Identify vulnerable native animals*, especially where roadkill may be significant at the population scale and where adjacent lands are managed for conservation or within managed areas/corridors. Reduce risk of death on road (slower vehicle speed limits). Exclude animals such as kororā and kiwi from edges using fencing. Raise flight paths using roadside plantings or barriers). *Construct new areas of habitat such as stormwater wetlands on the same side of the road as natural wetlands to minimise wetland birds crossing*. Do not rely on signs as research shows permanent warning signs are not effective at mitigating roadkill. • Do not create habitat in places where native animals will be susceptible to being killed by traffic – for example, replace mown grass with gravel or unmown swales; do not plant highly-attractive food species for vulnerable birds on road edges, unless high above the road (eg, tree lucerne for kererū).

Edge-effect class and contributing feature	Actions to decrease the severity, duration or scale of the adverse effect *or to create benefits*
Ecological traps	Identify potential for ecological traps created by road culverts, catchpits and noise walls, and treat to either exclude vulnerable fauna or allow their passage (eg, grates that will exclude kiwi from culverts). Ensure water bodies (eg, drains) are not ecological traps in summer, when temperatures can reach lethal levels by providing plant shading over water and ensuring road runoff passes through soil before entering watercourses).
Air emissions and wind	
Contaminant deposition to adjacent plants	Minimise generation of dust during capital projects (eg, using mulches, temporary irrigation or polyacrylamides). Reduce movement of dust into vulnerable ecosystems using irrigation, water trunks and/or temporary filter or shelter cloth.
Radiated and reflected heat and light	Effects are exacerbated by low-humidity winds, unshaded and dark surfaces, and surfaces with high thermal mass. Use light-coloured surfaces. Provide afternoon shade. Buffer vulnerable edges to reduce wind penetration, especially if a small patch (less core). Create narrow, short gaps with uneven canopy heights so wind tunnels are not created.

Table 5.4 Mitigation actions suitable for existing roads that decrease severity, duration or scale of adverse road edge-effects, including roadkill and fragmentation. Actions focus on maintenance. Actions likely to enhance biodiversity values are italicised.

Edge effect class and contributing feature	Actions to decrease the severity, duration or scale of the adverse effect *or to create benefits*
Noise and vibration	
Noise generation	• When re-sealing, use low-noise-generating road surfaces where vulnerable animal species/ecosystems are present and noise impact is over large areas (eg, open landscapes and/or water). • Manage signs to reduce traffic speeds at times (eg, nights or seasons) that align with key activity or vulnerability period of vulnerable animals (eg, breeding, dispersal, when food near the roads is abundant).
Light	
Light presence	*Remove or do not replace existing lighting in high ecological value areas where it is not needed.*
Light spread	Manage roadside vegetation to limit spread of headlights and streetlights at vulnerable sites (eg, over water or tight corners where light travels a long way) – that is, allow taller, denser plants.
Light duration	Where streetlights can be manipulated, control intensity and duration to mitigate impacts (eg, dimming during petrel maiden flight period).
Background light	Work with owners of adjacent land to mitigate adverse effects of light, especially in areas with low background light.
Stormwater runoff	
Runoff contamination	• Adopt road sweeping and catchpit maintenance frequency that optimises sediment capture, with higher frequency near sensitive ecosystems and areas with higher contamination (not uniform treatment). • Minimise areas of bare soil along road edge by controlling mowing height to stop risk of scalping and maintain dense cover, minimising grading (and carry out grading when plants are growing fast to quickly stabilise bare surfaces), and minimising the area receiving herbicide, especially around water tables, drains, bridges and marker posts. Ensure drains are stable with minimal erosion. • Ensure drains are not ecological traps (eg, in summer, water in drains can reach temperatures that kill fish). Use plants to shade water.
Runoff treatment	Encourage vegetated swales and water tables that are maintained by mowing rather than herbicide to maximise filtering of road runoff through plants and soil.

Edge effect class and contributing feature	**Actions to decrease the severity, duration or scale of the adverse effect *or to create benefits***
Hydrology	
Effect on groundwater	Enhance infiltration of stormwater into soil adjacent to roads by maintaining vegetation cover (which slows water flow and retains soil pore volume).
Effect on adjacent vegetation	Do not undertake earthworks or change stormwater discharge locations near the drip zone of trees, drought-tolerant herb fields, or low-stature wetlands.
Habitat modification, landscape effects, fragmentation	
Fragmentation of remnant ecosystems	*Reconnect remnants by promoting natural regeneration of suitable native species using mowing, or targeted removal of competing weeds.* Do not build new gravel storage/infrastructure areas in fragments of habitat in landscapes where habitat is already scarce, and in continuous areas of core habitat (put them adjacent to farmland), and decommission existing infrastructure areas in these habitats.
Fragmentation of native animal populations	*Increase size of fragmented remnants by buffering and/or adding habitat features generated by maintenance such as clearing tree falls or removing/pruning tree hazards. Target areas are likely to include degraded remnants, or young habitat (see ‘Enriched ecological features’ below).*
Barriers created by absence of trees	*Maintain trees along edges in ways that maintain their health (eg, stop damaging herbicides entering root zone; use targeted pruning rather than slashing that creates extensive branch dieback) and encouraging growth of tree canopy over road surface in suitable, defined places* (specific ‘permitted’ trees may be defined in highway management plans). Maintain continuous vegetation edges where flight paths of identified species (such as bats) cross roads.
Barriers created by ongoing disturbance	*Ensure any herbicide areas around marker posts, barriers, signs, culverts and/or water tables are no greater than minimum requirement and complement with mowing to minimise herbicide area*. Minimise areas of bare ground that are regularly sprayed and vulnerable to erosion or establishment of non-native plants.
Barriers created by adverse microclimates	• Use maintenance to develop and sustain edge-specialist plant communities that create multi-layered, dense edges that are resilient and more effectively buffer adjacent ecosystems (eg, by using variable mowing heights and times, and selective placement/types of herbicides). • Preserve tree canopy on north side of road to enhance shade of ecosystems vulnerable to drying out or high temperatures.
Increased ‘safe’ road corridor ‘edge’ habitat	Enhance value of edge habitat for specific plants by controlling mowing height and frequency to benefit low-growing native turfs and minimise area sprayed in these communities.
Increased native seed sources	Control pest plants, remove browsers and develop favourable vegetation control regimes to increase suitable native species and their pollinators and dispersal fauna, especially in depauperate landscapes.
‘Core’ habitats	Maintain edges in ways that maintain a dense buffer of plants along the edge that reduces light, noise, and wind penetration (eg, regular minor pruning rather than occasional deep cut-backs that expose views and wind into adjacent forest).
Spread of pest plants to natural areas	• *Use maintenance practices that maintain a dense native or non-weedy cover as this helps exclude establishment of new plants.* • *Do not undertake practices that spread weeds, such as mowing that scalps soil or spreads weed plants (eg, montbretia, Tradescantia, Aristea). Do not create bare soils near pest plants, especially herbicide-resistant species (eg, agapanthus).* • *Maintain gravel/aggregate stockpiles and surrounds free of weeds* (and ensure supplying quarries have adequate weed control to minimise risk of weeds in gravel). • *Prevent non-native/pest plants spreading along water tables and into natural drainage features*. Ensure drain maintenance does not spread fragments of weeds (eg, alligator weed, seed of Himalayan balsam) by using cleaning and other biosecurity protocols. • Monitor for new (outlier) pest plant species in buffers around high-value conservation areas and eliminate when found to reduce future liability, especially plants that will drive permanent changes in community structure (eg, nitrogen-fixing legumes in naturally infertile areas).

Edge effect class and contributing feature	Actions to decrease the severity, duration or scale of the adverse effect *or to create benefits*
	• *Eliminate palatable pest plants found in ungrazed road corridor where such species are absent in adjacent farmed landscapes* (eg, *Prunus*, privets).
Enriched ecological features	Identify opportunities to enrich areas that could be habitat for target native species, especially in immature planted or regenerating areas of forest. Such opportunities include salvage and specific placement of fallen or removed trees and their epiphytes as habitat or for regeneration of edges. Tree and shrub prunings from roadside maintenance can be used as mulch or soil amendment.
Road users/road neighbours	
Neighbours of protected areas assist conservation outcomes	Discuss how maintenance can assist conservation outcomes where neighbouring land is managed for conservation.
Cumulative effects from linear infrastructure	Identify where railway or transmission lines, water races or drainage schemes align or cross a road corridor, particularly where the combined corridor is much wider or connects ecosystems. Assess opportunities to achieve greater biodiversity benefits, especially in depauperate landscapes. Assess risks where habitat gaps and weeds are exacerbated.
Weed pressures from adjacent land	• Monitor and react to weeds establishing from plantation forestry post-harvest, actively eroding areas, and new land uses that include weed species (eg, olives, pest pines, palms in landscaping). • Discuss with owners/managers of adjacent land ways to reduce risk of plant spread (eg, agapanthus from driveways; privet or cotoneaster from hedges; broom and pampas from plantations near harvest).
Illegal dumping	Eliminate vehicle access at ‘fly-tipping’ sites.
Gross pollutants	Identify roadsides with high gross pollutants and/or vulnerable receiving environments and increase the frequency of litter sweeps in these areas. Consider verge mowing that creates a sharp edge against which litter is easily visible and efficiently collected.
Increased fire risk	• Maintain rest areas with potential fire places to minimise long grass and accessible flammable material (eg, gorse, pine trees). • Time main verge mowing for December to remove spring growth flush before holiday period (and dry period). • Stop using herbicide in ways that create high fuel load.
Habitat disturbance from access to edges	• Maintain edges so that roadways and paths at rest areas are defined (and limited). • Maintain bulky vegetation as buffers with natural areas to restrict access to high-value areas adjacent to/within rest areas. • At pullovers with access to waterways, coastal areas, vulnerable alpine environments, and sites with views, install signs that alert people to damage from weeds, dogs, fire and off-path traffic.
Roadkill	
Roadkill – non-native animals	• Record roadkill locations. If roadkill is locally concentrated (eg, bridges), consider methods of enhancing kill rates of non-native mammals with trapping, and ensure safe access and parking areas for people servicing the traps. • If roadkill is scavenged by hawks, add maintenance that removes roadkill well away from road verge early in mornings as part of road inspection.
Roadkill – native animals	• Record roadkill locations and native species. Identify vulnerable native animals, especially where adjacent lands are managed for conservation or within managed areas/corridors. • Use information to identify potential for ecological traps of road culverts, catchpits and noise walls, and treat to either exclude vulnerable fauna or allow their passage (eg, grates that will exclude kiwi from culverts).

Edge effect class and contributing feature	Actions to decrease the severity, duration or scale of the adverse effect *or to create benefits*
	• Use information to identify ways to mitigate impacts (eg, reducing road-edge habitat that attracts native animals or their food; replacing mown grass adjacent to wetlands with gravel or vegetated swales; pruning near-roadside tree lucerne to reduce mortality of kererū).
Roadkill – native plants	Select and apply herbicides in ways that reduce ecological harm to non-target species (eg, cut/paste, wick boom or a grass-specific herbicide where natives are broad-leaved species (or the reverse); mow at heights and at times that promote native herb retention (not scalping, allowing native seeding)).
Air emissions and wind	
Contaminant deposition to adjacent plants	Manage dust generation and its spread into roadside vegetation (eg, covering, revegetating, or replacing surfaces with materials that reduce emissions).
Radiated and reflected heat and light	Maintain vegetation height, density and location to effectively buffer vulnerable edges.

5.3.3 Prioritising measures to manage road edge-effects

This section recommends actions needed to identify, measure, and prioritise measures that avoid or mitigate adverse road effects, and strategies that deliver biodiversity benefits. Monitoring and evaluation are needed to report on progress towards Waka Kotahi environmental goals, develop cost-effective design and maintenance measures, and prioritise effects management across new and existing roads. This section recommends establishing national and regional baselines using existing databases combined with field surveys. These baselines identify areas with high road pressures and/or high biodiversity values and/or high sensitivity to road pressures or very low biodiversity values. Section 2 (‘Road edge-effects assessment’) and the case studies (sections 3 and 4) tested a four-step method that identified useful databases and information gaps. These gaps need to be urgently filled by:

- developing methods to monitor and report pest plant populations and agrichemical use
- research on effectiveness of buffers and critical ecological features
- fundamental research to measure the effects and determine if thresholds are present for adverse effects of road-derived noise and light on native birds, lizards and invertebrates (noting thresholds may not be present).

It is imperative to characterise biodiversity benefits using monitoring combined with management actions (eg, Before–After Control–Impact (BACI) studies). This approach is needed to build on current anecdotal successes in reducing roadkill of specific native birds, especially where populations are being adversely affected and/or are increasing due to predator control in the surrounding landscape. Without such BACI studies that produce reliable data, resources may be spent on biodiversity mitigation measures that are unnecessary or do not work.

5.3.3.1 Rationale for targeted New Zealand research

There are two reasons New Zealand-specific research on road edge-effects is required. First, New Zealand has unique, highly endemic fauna and flora that are likely to respond differently to some road pressures (noise, light, air emissions, stormwater runoff, disturbance and fragmentation). These responses are also influenced by the unique vulnerability of New Zealand flora and fauna to pressures that limit their abundance. These pressures are exerted by introduced mammal herbivores and carnivores and self-established non-native flora that is still expanding into favourable areas. New Zealand roadsides probably have a higher proportion of adventive flora than many overseas roadsides, reflecting low tolerance of most native species to frequent disturbance, and the presence of a few very aggressive adventive species, some of which are also adapted to high exposure and low nitrogen levels (legumes). In some cases, seed production of these adventive plants is enhanced by preferential pollination by adventive invertebrates (eg, bumblebees pollinate broom, clovers, lotus and lupin; Goulson, 2013). These differences mean detailed studies of key New Zealand taxa at a range of road sites are needed to derive relevant, practical knowledge of roading impacts (positive and negative) and effective mitigation methods.

Second, reliable data and research are needed to develop effective effects management strategies for New Zealand fauna and flora. Without this information, strategies are not necessarily (a) necessary and (b) effective – for example, strategies to enhance connectivity across highways for bats, or between forest fragments for forest-dwelling birds, or lighting mitigation strategies to reduce effects on Westland petrels and nocturnal native animals. Where mitigations are costly, this represents both a waste of resources and lost opportunities to invest in actions that benefit New Zealand's biodiversity and contribute to Waka Kotahi commitments.

While the ecological responses to different road pressures (noise, light, air emissions, stormwater runoff, disturbance and fragmentation) identified in international literature are likely to differ in New Zealand due to our unique endemic flora, the types of pressures are likely similar, so they do not require research. However, calibration is required as many overseas studies include roads with higher daily traffic volumes than are typical of the majority of New Zealand highways, which receive less than 5,000 vehicles/day (Figure A.1 in Appendix A). Furthermore, many studied roads, particularly in the United States, are wider than the single-lane carriageways typical of New Zealand highways, with wider shoulders. Edge effects related to vehicle air emissions, noise, and stormwater runoff in overseas studies therefore tend to reflect greater impacts generated by higher vehicle densities and larger footprints. Road runoff in some overseas studies is also impacted by use of salt to mitigate ice, but salt is not used in New Zealand. Road corridors in parts of Australia and Europe (eg, Spain) tend to be much wider than typical New Zealand lowland landscapes, with more consistent tree canopy/woodland, reflecting their historical use as 'droving' paths for herds of cattle and sheep across landscapes. These large, continuous road verges may offer greater biodiversity benefits, although, as in New Zealand, such benefits are highest in areas where few natural ecosystems remain.

5.3.3.2 National measures of edge-effects

Establishing baseline measures to support long-term monitoring of effects of roads on biodiversity complements shorter-term, targeted research. Ten potential indicators were presented in Table 5.1 and Table 5.2. These cover the range of established road edge-effects identified in the literature, with the exception of air quality, which was considered to have highly localised impacts in New Zealand given relatively low traffic volumes except in some cities. The following four indicators can be derived from remotely sensed biodiversity measures available at regional and national scales, combined with Waka Kotahi RAMM data (which currently do not include ecological assets). These form a minimum baseline from which longer-term monitoring of edge effects can be reported:

- Modelled noise
- Streetlights
- Fragmentation
- 'Core' ecosystems.

Research on effects of road noise and artificial light on a range of New Zealand fauna is needed, particularly on the groups most likely to be adversely affected: nocturnal fauna, forest and wetland birds, invertebrates exhibiting 'flight to light' behaviour, and species such as bats and ruru that feed on such invertebrates.

Measuring population densities of targeted fauna at increasing distances from roads with a range of traffic intensities and lighting would inform the size of the ‘road-effect zone’ in which adverse road impacts extend into surrounding landscapes. Without such information, effective mitigation cannot be designed, and costly interventions such as noise walls or bunds, or compensation (such as habitat restoration in areas impacted by noise or light), could be both a waste of resources and a lost opportunity to benefit biodiversity.

Population density studies are needed because presence of an animal does not mean a habitat is suitable. Anecdotal evidence indicates roads can create habitat sinks in farmed areas with low native cover, as weka and kiwi use residual shrubland along roadsides, exposing them to roadkill. Populations of both common lowland forest birds and wetland birds should be included as these are most likely to be habitat-limited, so they benefit from extensive roadside revegetation and stormwater wetland construction. However, studies are also needed to identify the potential threat of roadkill to at-risk/threatened species. Studies should include roads through large areas managed for conservation (eg, national parks), as well as depauperate lowland areas. The latter is where roadside habitat could either permanently increase the long-term carrying capacity of a site, or adverse effects could limit the long-term carrying capacity, regardless of any benefits of predator control or additional planting. Capital roading projects in lowland areas typically include extensive mitigation planting and regeneration (eg, SH16/18 case study); however, most of these areas are exposed to road noise and/or light. Areas of highways with sections of noise walls and/or topography that delivers different levels of noise, lighting, and different locations of habitat offer opportunities for comparative research. Specific visual or other monitoring methods may need to be developed for birds, as conventional 5-minute bird counts are confounded by traffic noise.

Fragmentation indicators will be more accurate when research delivers data on what networks of patches and patch areas favour persistence of mobile native bird and invertebrate species of forest/shrublands. This research will identify distances that form barriers to movement of native species, and interactions with predators (eg, current research on cat movement in agricultural landscapes by Cathy Nottingham, University of Auckland). Aligned research could inform the potential of roads to enhance management of specific pest mammals – for example, using existing road crossings as trap-points (eg, bridges), designing ‘predator pinch points’ in capital projects where landscape-scale pest control occurs, or designing ‘out’ predator access points (eg, culverts, bridges).

5.3.3.3 Project-level measures of edge-effects

Four measures of road edge-effects are currently impractical to use at a national scale, but useful to apply to capital projects to monitor changes driven by road pressures on components of ecosystems. These indicators would be used to establish baselines before construction, which could then be measured through the defects-liability period and into maintenance. In future, remote sensing may allow some of these indicators to be cost-effectively mapped, particularly relating to plants with specific ‘spectral signatures’ (eg, pines, gorse). The four indicators describe:

- ecosystem degradation or improvement
- presence of pest plants/ecological weeds
- weed buffers
- critical ecological features.

The level of ecosystem degradation along roadsides is strongly linked to the construction footprint of a project, specifically areas where soils and plants have been removed. This needs to be recorded. In most cases, a substantial proportion of the footprint is then rehabilitated to buffer adjacent native ecosystems and/or create new indigenous habitat, depending on locations (eg, SH16/18 case study). The biodiversity values of such areas are expected to improve over time as vegetation and soils develop; however, values can be degraded in the absence of suitable maintenance or potentially increasing disturbance from traffic (eg, SH16/18 case study). A range of strategies can be deployed to accelerate development of biodiversity values, including use of critical ecological features. However, the literature review found no New Zealand research on the effectiveness of road buffer-planting and no New Zealand research on the habitat values of rehabilitated roadside planting that considers the edge effects of road noise, light, weeds, and disturbance on native birds or invertebrates.

The most cost-effective and practical way to deliver critical mitigation research is to embed research through capital projects. This requires baseline data (as identified in Table 5.3 and Table 5.4) and enough flexibility in capital projects to include both ‘controls’ of standard (ie, Business As Usual) practice and ‘alternative mitigations’ that deliver biodiversity benefits/less impact. Two examples are (a) design criteria for effective buffers of light and low humidity for forest edges and (b) a method to accelerate and broaden values of new ecosystems being rehabilitated (eg, using wood, new leaf litter layers). The distance over which road edge-effects are reflected in vegetation composition within short-statured communities also needs to be identified as these define the quantum of mitigation; these communities contain edge-adapted and exposure-adapted species, and effects may be more strongly linked to hydrological changes (influenced by soils and road runoff) than ‘exposed edge’.

Measures related to weeds/ecological pest plants would benefit from development of a standard method to identify weed distribution along highways that is safe and cost-effective – in particular, enabling the identification of weed outliers. The potential spread and ecological impact of a suite of representatives and weeds could then be predicted. This would inform region-specific priorities for establishing weed buffers with adjacent land, particularly DOC-managed land. Such weed mapping should be applied to new capital projects on a finer scale. This would proactively identify new weed populations that establish during construction, be used at the project defect liability stage, and provide an early indicator of future operations and maintenance liabilities. Effective road design and effective operational practices that prevent weeds spreading into, and along, road corridors would be useful. These are likely to include reducing bare ground and agrichemical use. Both case studies (section 3 and 4) give examples of practices that influence the establishment and spread of pest plants.

5.3.3.4 Research on roadkill

The final measure needed to understand the edge-effects of New Zealand roads is roadkill. Although vehicle–wildlife collisions in New Zealand tend to be seen as inconsequential, and even beneficial because the majority of observed roadkill are pest mammal species, the literature review, together with limited grey literature, indicates localised populations of some large native birds are probably vulnerable to roadkill (Figure A.5 and Figure A.6 in Appendix A). Vulnerable species are typically ground dwelling; flightless or walk across roads; large; slow moving; and long lived. Such species are most vulnerable where species distributions overlap with roads, and where they are either attracted to roadsides (eg, for habitat or roadkill) or not ‘repelled’ by roads. The most numerous recorded native roadkill are species that are not threatened: pūkeko and kāhu/harrier hawk, and in one Wellington site, kererū. Eight potentially vulnerable large native birds were identified: kiwi, weka, kororā, pāteke/brown teal, kea, tarāpunga/red-billed gull, and whio. An increasing area and efficacy of predator control across New Zealand (eg, through Predator Free 2050) means the relative impact of roadkill could be expected to increase over time.

Four areas of work would help assess effects of roadkill. These need to be delivered in order. First, use grey literature and interviews to gather information that identifies what bird species and road sites in New Zealand exemplify possibly significant mortality by vehicle strike, and what species’ traits and site attributes characterise the above examples. Second, develop a roadkill reporting method that includes both large and small birds, and other creatures (eg, some invertebrates). Small birds and invertebrates are under-represented because carcasses are quickly removed, break down quickly, and may be thrown further from the road. The method must be applicable to extensive conservation areas as well as to roads passing through small lowland forest remnants. The roadkill method needs to consider scavenger removal. Third, measure current rates of roadkill of these species at these sites and also in areas where ‘vulnerable’ species and roads overlap (in case anecdotal records/reports are wrong). Use the data to identify how roadkill varies by season and year, and to assess if roadkill significantly changes the population trend of these species (a) at these sites and (b) nationally. Once the roadkill reporting method is developed, it can be applied to measure the efficacy of a range of measures already used to mitigate roadkill at sites, and for species identified in the first step.

5.3.4 Conclusion

Roads and road corridors have effects on biodiversity that extend from the trafficked surfaces, through verges and drains managed by roading authorities, and into adjacent landscapes. These ecological effects are typically measured as they extend out from the road surface to determine the significance and severity of ‘road edge-effects’. The pressures created by roads and traffic are generally well-characterised internationally, and include noise and vibration, ALAN, road stormwater runoff (and spills), air emissions, hydrology, habitat modification, habitat fragmentation, and roadkill. Many of these effects are permanent (eg, effects generated by vehicle movement and road runoff). Effects related to traffic density and impervious area are likely to increase over time; traffic continues to increase, and road upgrades generally increase impervious surface area and the cuttings and fill slopes (to enhance traffic speeds), while few roads are removed.

We mapped general road edge pressures and pressure points at national and regional scales using a desktop method that combined existing Waka Kotahi, LINZ, local government (eg, significant ecological or natural areas) and environment data sets. However, field assessments were needed to identify edge-effects caused by most pest plants, roadside maintenance (eg, agrichemical application and mowing) and road stormwater runoff. The combined mapping identified areas with high road pressures and/or high biodiversity values (inferred from habitats and adjacent land management).

Very little New Zealand evidence identifies how far most road edge-effects extend from roads (other than some vegetation changes), what road-related effects create a barrier for many species (and therefore contribute to fragmentation), or the effects of roadkill. New Zealand has unique, highly endemic fauna and flora that are likely to respond differently to some road pressures (noise, light, air emissions, stormwater runoff, disturbance, and fragmentation). These responses are also influenced by the unique vulnerability of New Zealand flora and fauna to pressures that limit their abundance. These pressures are exerted by introduced mammal herbivores and carnivores and self-established non-native flora that is still expanding into favourable areas. New Zealand roadsides probably have a higher proportion of adventive flora than many overseas roadsides, reflecting low tolerance of most native species to frequent disturbance, and presence of a few very aggressive adventive species.

New, fundamental research is therefore critical to quantify the effects of road-derived noise and artificial light on a range of native birds and other fauna most likely to be affected (ie, nocturnal fauna, some forest and wetland birds). This research is needed to quantify the size of the ‘road-effect zone’ within which adverse road impacts extend into surrounding landscapes. At the same time, studies are needed to identify where roadkill may threaten nationally vulnerable species. This information will inform development and testing of effective effects management strategies for New Zealand fauna and flora. A cost-effective way to test mitigation research is to embed alternative designs in capital projects, including using BACI studies. Without this research, mitigation and compensation actions may be done that are not necessary and/or not effective. The current knowledge gaps on effects of roads on New Zealand species and environments mean some effects management strategies are being used that are ineffective, so they represent lost opportunities to invest in actions that will contribute to Waka Kotahi commitments on biodiversity.

The impacts of roads on New Zealand biodiversity are overwhelmingly negative in natural areas with high intactness and low fragmentation, and where roads reduce the size or quality of remnants across large areas of lowland New Zealand where very little native forest or wetland remains. In such depauperate lowland areas, lack of suitable habitat limits native species abundance and fragments populations, preventing movement of less mobile species. However, suitably designed road corridors with expanded, buffered remnants may deliver substantial biodiversity benefits in these landscapes, especially for common, but highly valued, birds and invertebrates. This report outlines information needed to design, construct and operate roads that invest in effects management and enhancement actions to deliver net positive impacts on New Zealand biodiversity.

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Appendix A: Infographics

Figure A.1 Highway traffic volumes and road density are unevenly distributed

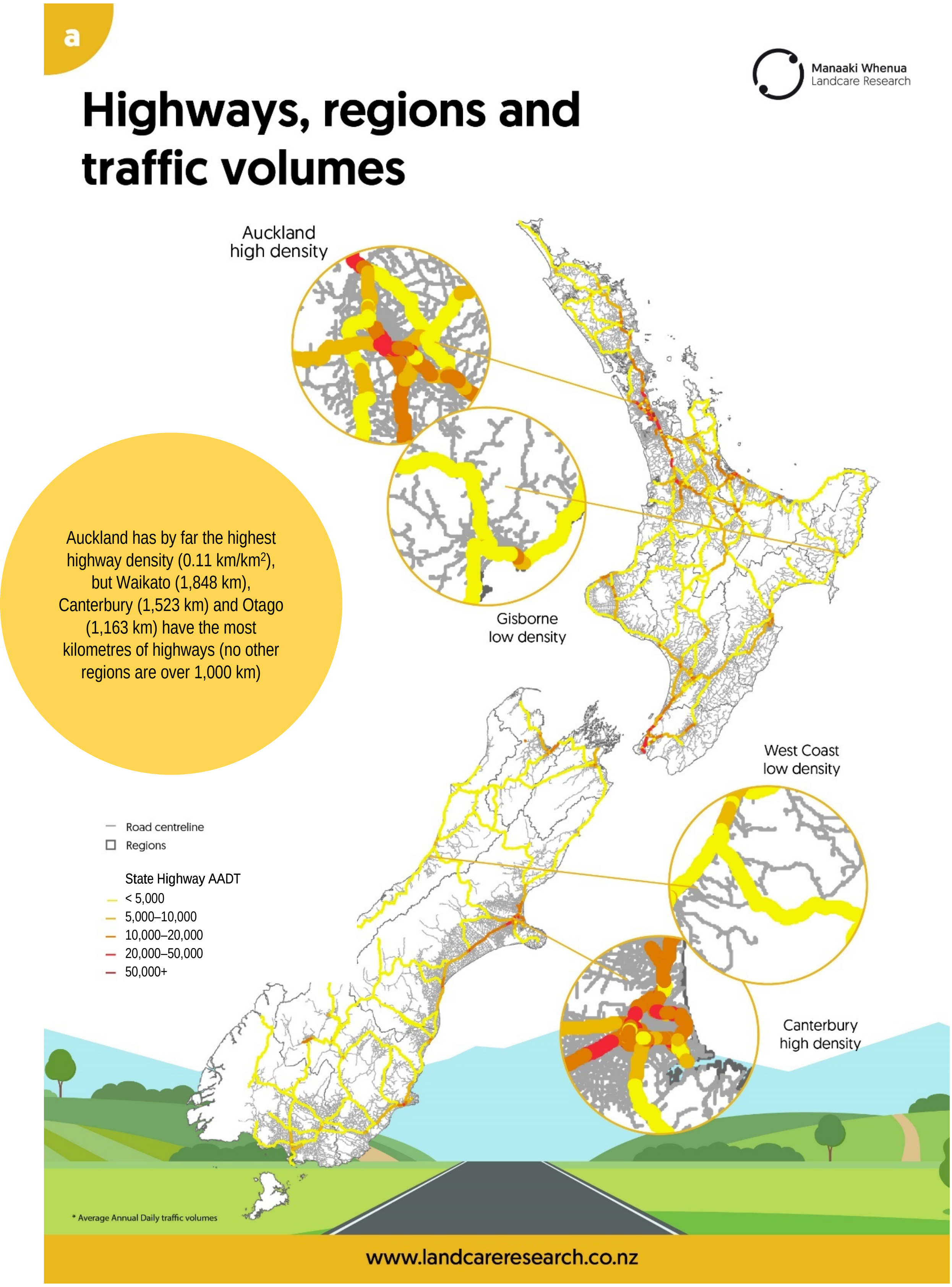

Figure A.2 Highway verges may act as refuges in depauperate landscapes

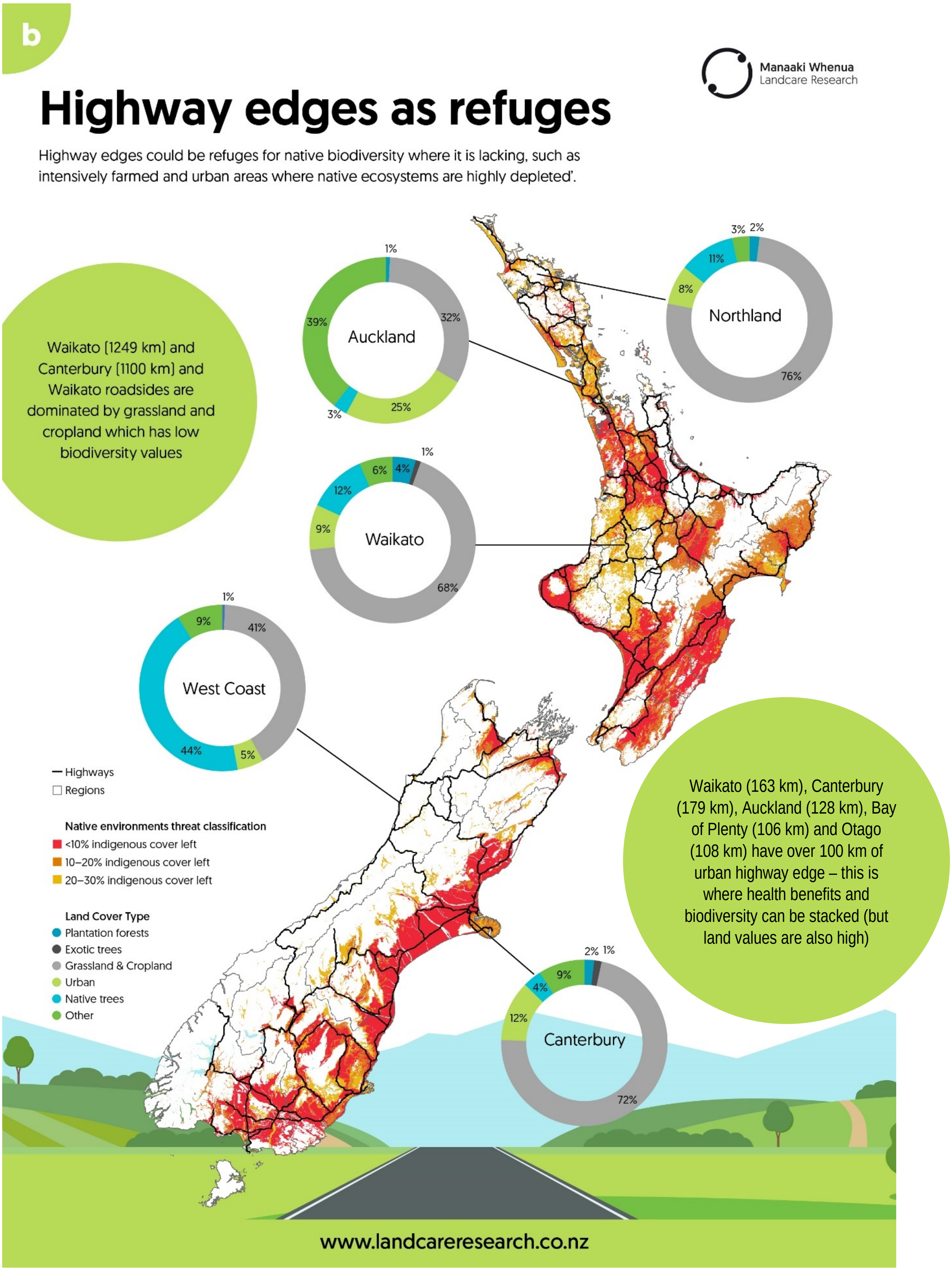

Figure A.3 Highways impact conservation areas

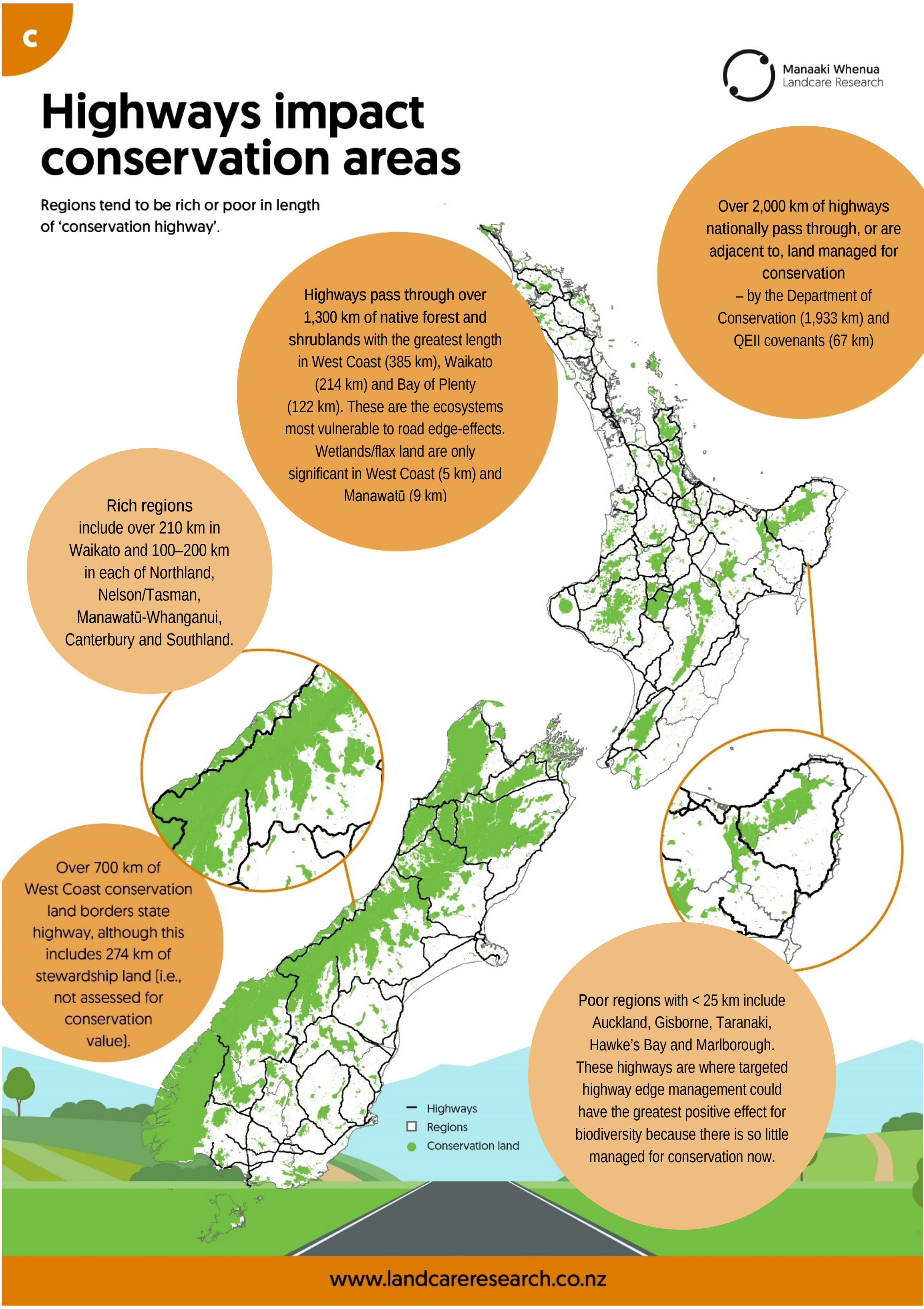

Figure A.4 Sensitive sites: where highways with lighting intersect with wetlands, coasts, and conservation areas

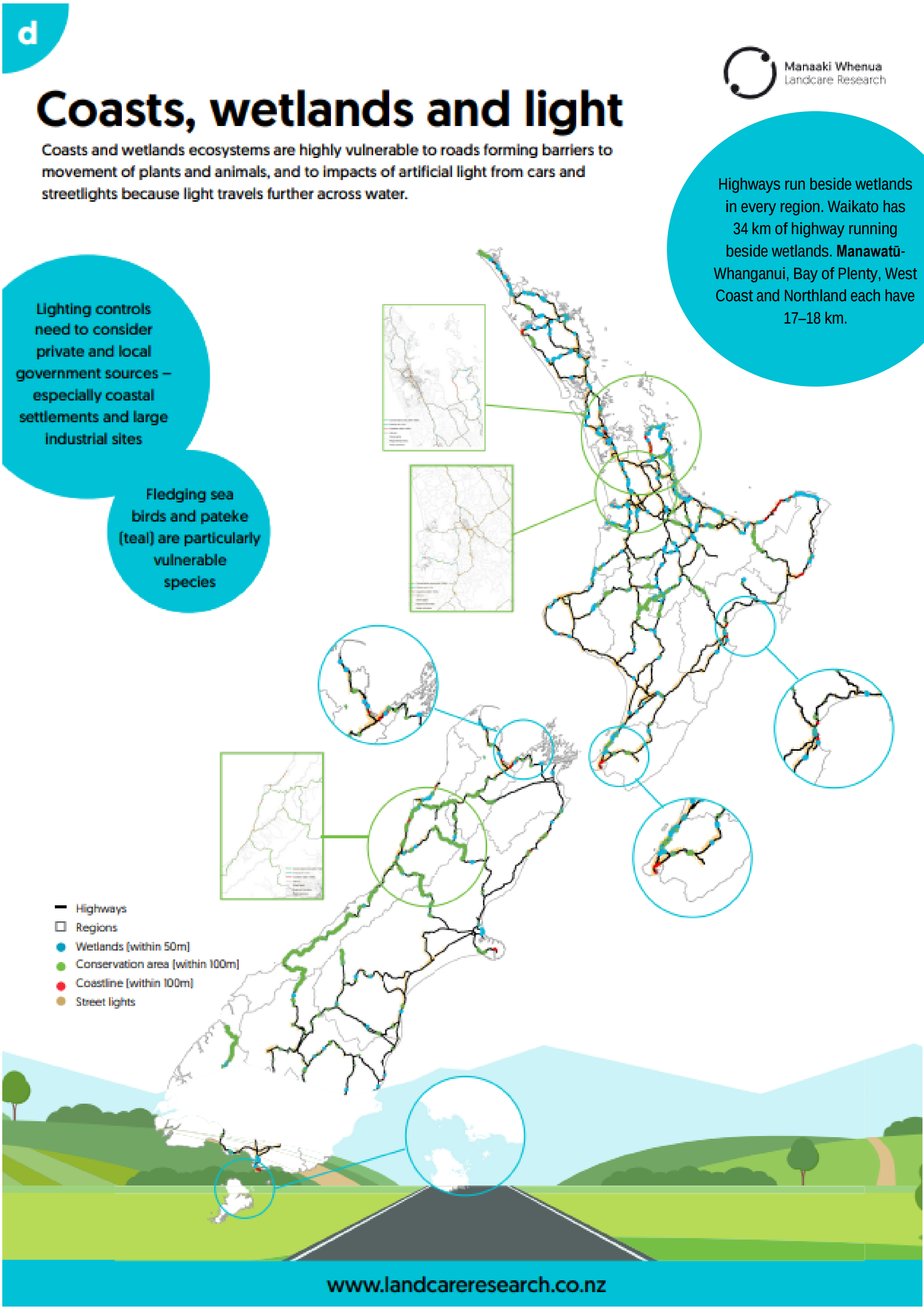

Figure A.5 Vehicles as predators of native birds: Impacts and contributing factors

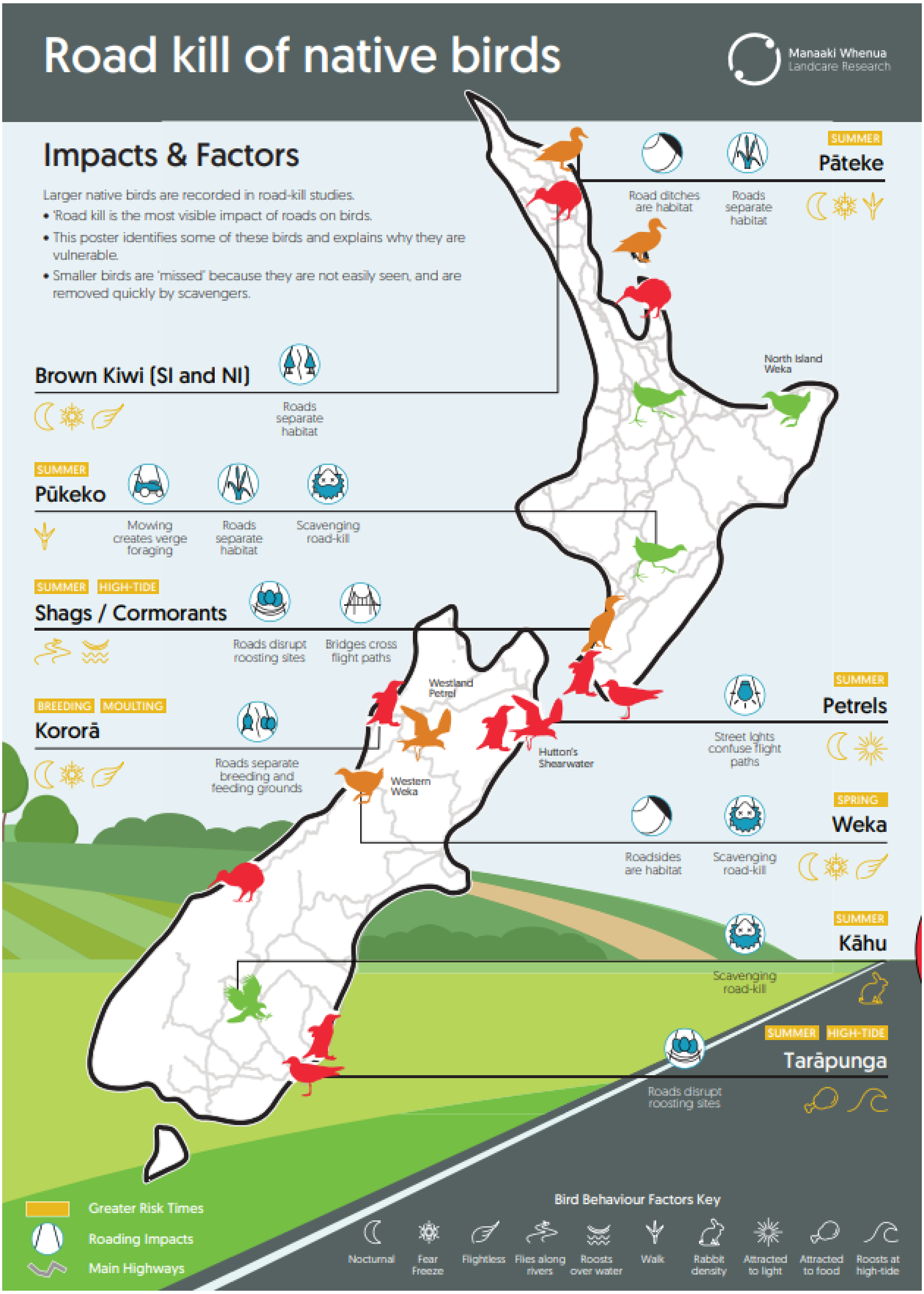

Figure A.6 Vehicles as predators of native birds: Mitigation

Impacts of roads on individual wildlife and populations

Figure A.7 shows four vertical zones, from adjacent land outside the road corridor (olive green) to the road surface and gravel shoulder (grey). Road construction permanently removes habitat in grey areas; road verges (dark green) are maintained by frequent cutting and/or herbicide to retain required sight lines and frangibility but can provide habitat for some species. Adjacent areas with infrequent physical disturbance form habitats and corridors for some species. Road traffic, stormwater runoff, air, heat, and particulate emissions influence the habitat quality of ecosystems in the road verge and adjacent land. Dotted arrows indicate that some animals that enter the road corridor or verge may be vulnerable to roadkill. The distance at which effects occur varies with species, traffic volumes, traffic speeds, and mitigation methods.

Figure A.7 How highways impact conservation areas (adapted from van der Ree et al., 2015, original illustration by Zoe Metherell).