Climate Change Impacts and Implications for New Zealand to 2100

Synthesis Report: RA2 Uplands Case Study

Upper Waitaki Catchment

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CONTENTS

HIGHLIGHTS

- The Uplands Case Study undertook loosely coupled systems modelling to better understand the potential impacts and implications of climate change for the economy, environment and society in the upper Waitaki catchment from an integrated perspective. Systems modelling was used to evaluate scenarios linking global development organised along socioeconomic and representative greenhouse gas concentration pathways with selected aspects of New Zealand development both nationally and sub-nationally, e.g. the upper Waitaki catchment.

- Impacts and implications of climate change in the catchment will result from both direct and indirect effects of a suite of interacting biophysical, socioeconomic and cultural drivers operating across global, national, regional, and local scales.

- The regional climate including the study area is likely to become warmer and wetter, with some shifts in seasonal patterns. The number of hotter days ⩾ 25°C and colder nights ⩽ 0°C is likely to increase and decrease, respectively. Frequency of extreme events such as high rainfall or winds could increase as much as 10 to 15%, depending upon the magnitude of future global greenhouse gas concentrations.

- Global and national socioeconomic developments, such as changing commodity prices, will strongly influence the catchment. In some cases, those developments will outweigh the direct, local effects and impacts of climate change in relation to land-use change.

- The warming climate and changing precipitation and weather patterns is likely to increase the availability of suitable area for many weeds and reduce suitable area for some. Changes are very likely to vary over time, with some effects felt earlier than others. The shifting patterns of balance and timing will increase challenges to biodiversity and conservation management by shifting management and control priorities and possibly increasing the total pressure exerted by weed species on both native biodiversity and primary production.

- Hydrological modelling shows that water management will likely become more challenging and complex. While mean annual flows in the catchment are likely to undergo small average changes over the coming century, mean seasonal flows will likely show more pronounced changes, reflecting changes in weather patterns resulting from climate change. Changes in the seasonal patterns will affect the timing of storage and delivery of water for a range of uses.

- Annual pasture productivity is likely to increase overall due to increased plant growth resulting from the likely increase in precipitation and water availability and CO_2 fertilization effects from higher atmospheric CO_2 concentrations. Large seasonal changes, including summer feed gaps and more productive winters, could necessitate adaptation to shifts in the temporal availability of forage for livestock.

- Although not explicitly modelled, expected trends in climate change will likely have negative implications for tourism and recreation. For example, reduced snowfall and/or the ability to operate snow-making equipment could over time reduce the net number of days suitable for skiing in the catchment. Also, higher frequency of extreme events could increase risks of damage to important tourism infrastructure such as huts and tracks.

- Expansion of the range of wilding conifers would likely decrease water yield relative to current vegetation cover and help mitigate the increasing wildlife risk from climate change. However, that expansion is very likely to impact negatively on native biodiversity and primary production in complex ways, e.g. further invasion of tussock grasslands would reduce the extent and ecological integrity of native ecosystems and areas remaining in primary production.

- In summary, the uplands case study demonstrated that climate change, when considered in conjunction with broader socioeconomic developments, will likely increase uncertainty and risks and therefore increase challenges to policy, business planning, resource management, and societal resilience into the future. The ability to cope and adapt to changing risk profiles varies among scenarios and depends both on assumed socioeconomic developments as well as on the expected degree of climate change.

INTRODUCTION AND BACKGROUND

The CCII project

The "Climate Changes Impacts and Implications" (CCII) project was a four-year project (October 2012 – September 2016) designed to address the following question:

> *What are the predicted climatic conditions and assessed/potential impacts and implications of climate variability and trends on New Zealand and its regional biophysical environment, the economy and society, at projected critical temporal steps up to 2100?*

The CCII project brought together a strong research team with knowledge and modelling capabilities in climate, ecosystems, land and water use, economics, and sociocultural research to address the environment sector investment plan priority of "stronger prediction and modelling systems".

The project was based around the five following interrelated Research Aims (RAs) that provided new climate change projections and advancements in understanding their impacts and implications for New Zealand's environment, economy and society:

Research Aim 1: *Improved Climate Projections*

Research Aim 2: *Understanding Pressure Points, Critical Steps and Potential Responses*

Research Aim 3: *Identifying Feedbacks, Understanding Cumulative Impacts and Recognising Limits*

Research Aim 4: *Enhancing Capacity and Increasing Coordination to Support Decision-making*

Research Aim 5: *Exploring Options for New Zealand in Different Changing Global Climates*

The overall purpose of RA2 was to understand and assess the potential impacts of climate change and other key drivers in a set of case studies of five representative landscapes organised along an elevational gradient: alpine, uplands, lowland, coasts & estuaries, and marine environments (Fig.1). This synthesis report presents the results of the uplands case study.

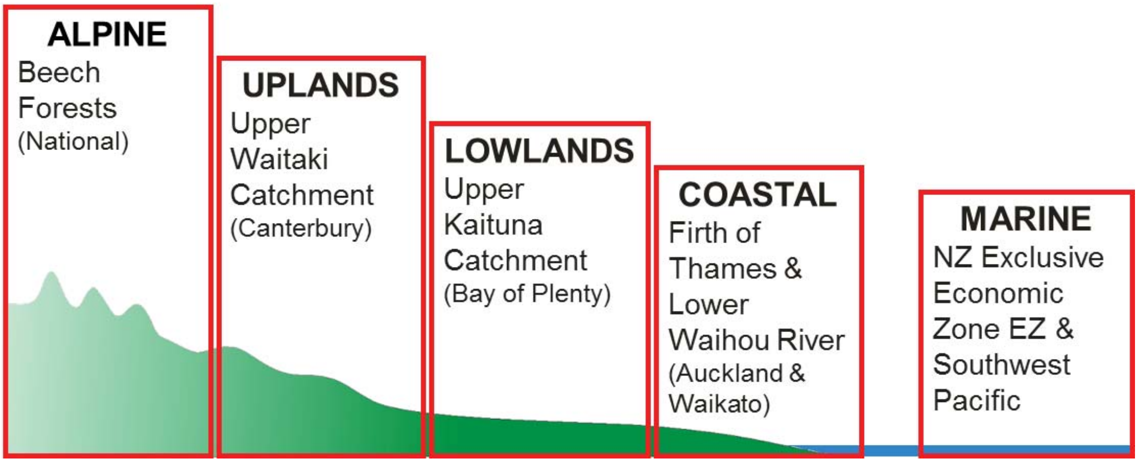

Figure 1: Conceptual drawing of the elevational gradient of the five CCII Research Aim 2 case studies.

Global and national context

The uplands case study operated within a broader global and national context (Fig. 2). At the global level, a new global architecture developed for the IPCC Fifth Assessment outlines the protocols for framing, modelling and evaluating a new generation of global climate change scenarios. Global scenarios combine 1) Shared Socioeconomic Pathways (SSPs, 5 in total) that organise future global developments according to a matrix of challenges to adaptation and mitigation; 2) Representative Concentration Pathways (RCPs, 4 in total) that specify standardised global greenhouse gas emissions trends; and 3) Shared Policy Assumptions (SPAs) that specify assumptions about future global developments in climate change mitigation policies.

The CCII project via RA5 (Frame & Reisinger 2016) also developed Shared Climate Policy Assumptions for New Zealand (SPANZ) that outlined how New Zealand might diverge from broader global assumptions and trends including policies targeting climate change mitigation, adaptation strategies, etc.

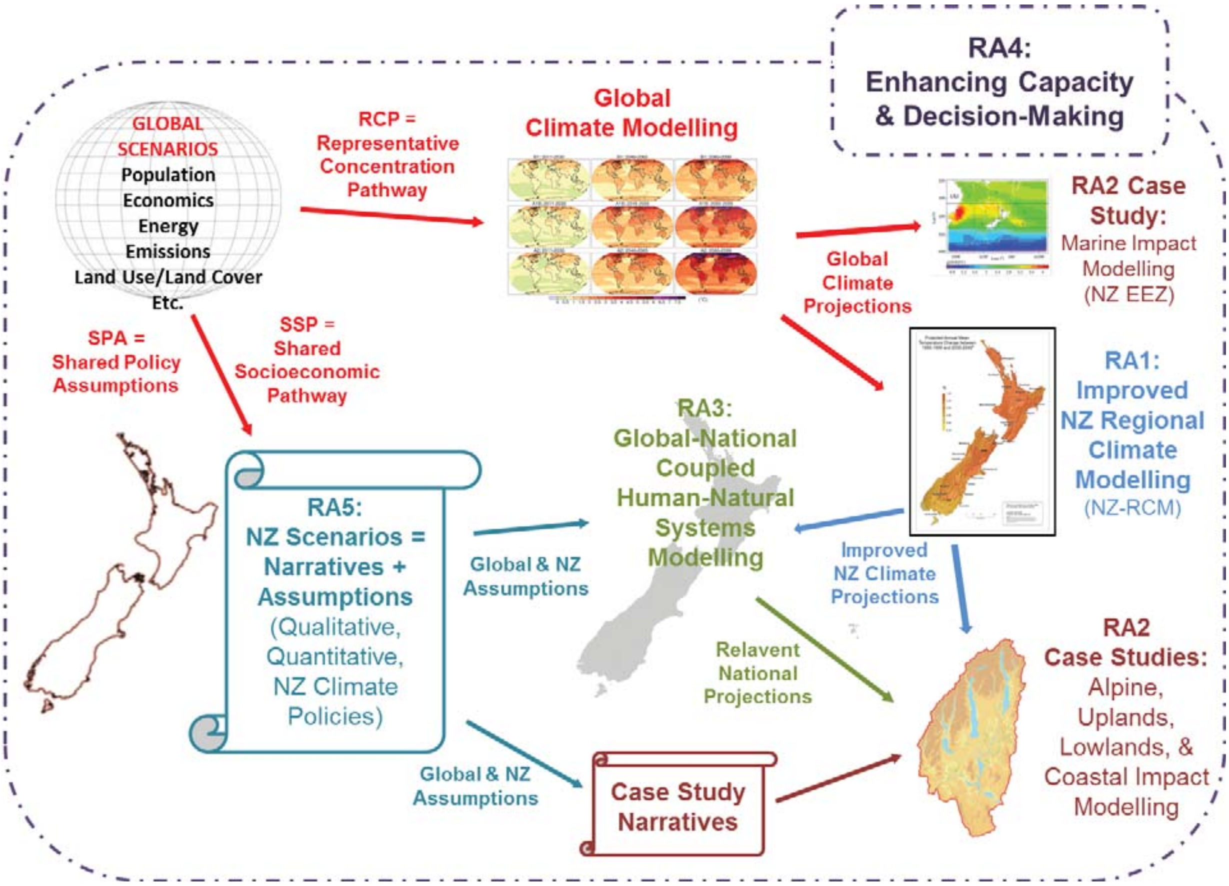

Figure 2: Uplands case study (lower right) in the broader CCII context including global climate change scenarios, climate modelling and integrated assessment modelling (black text and arrows) and the four other CCII research aims (coloured text and arrows).

Given available resources, the CCII team prioritised six of the possible 20 (5 SSPs x 4 RCPs) global scenarios to model, analyse, evaluate, and interpret (Fig. 3). Appendix A provides an overview of the global scenario architecture. For more details, consult the RA1, RA3, and RA5 synthesis reports, respectively, to learn more about: 1) improved New Zealand climate projections (Tait et al. 2016); 2) global-national integrated systems modelling (Rutledge et al. 2017); and 3) the global scenario architecture and New Zealand scenarios (Frame & Reisinger 2016) that together provided the broader context in which the uplands case study operated.

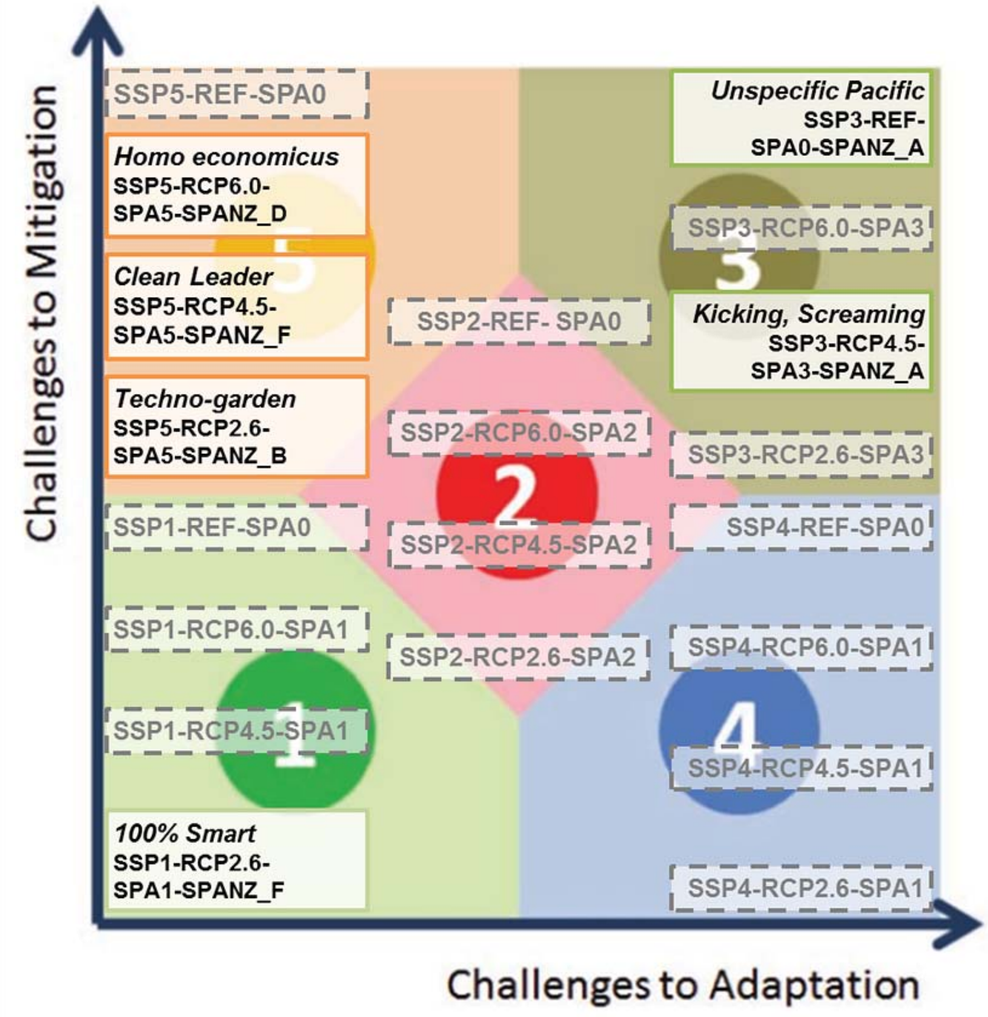

Figure 3: Six CCII scenarios (black) within the broader global scenario architecture. CCII scenario names come from the NZ scenario framework developed by RA5 (Frame & Reisinger 2016). Scenario nomenclature follows the global study protocol as follows: SSP = Shared Socioeconomic Pathway (1 to 5); RCP = Representative Concentration Pathway (2.6, 4.5, 6.0, REF) arranged vertically within each SSP to reflect increasing global GHG concentration pathways; Shared Policy Assumptions (0 to 5); SPANZ = Shared Policy Assumption for New Zealand (A to F).

The uplands case study

New Zealand's uplands environments encompass a diverse mosaic of land uses that provide essential ecosystem goods and services. Uplands make substantial economic and societal contributions to primary production, water quality regulation and supply for agriculture and hydroelectricity generation, and recreation and tourism. They also include internationally recognised iconic landscapes, rare and threatened ecosystems such as ephemeral wetlands – wetlands that temporarily hold water in the spring and early summer or after heavy rains, and important habitat for threatened and endangered species such as the South Island takahē – a rare relict of the flightless, vegetarian bird fauna that once ranged New Zealand. At the same time, uplands experience on-going or new pressures from several fronts, including pests and weeds, increasing land-use competition, soil erosion, wildfires, etc.

Climate change will impact the complex dynamics of upland systems, both directly and indirectly, in combination with other key drivers. Direct impacts will result as changing climate and associated weather patterns simultaneously alter the relative suitability and risks of land for different uses and the composition and patterns of ecosystems in complex and poorly understand ways. Indirect impacts will result from the effects of climate change experienced elsewhere in New Zealand and globally that feedback into regional and local dynamics via interacting economic, sociocultural, and environmental pathways, such as policies targeting carbon sequestration via afforestation.

STAKEHOLDER ENGAGEMENT AND CASE STUDY SELECTION

Case Study Selection

The RA2 uplands case study team compiled an initial list of candidate case study areas based on an internal review of available knowledge, models, and data. Following informal consultation with a broad range of stakeholders representing conservation, primary industry, government, and iwi, the Upper Waitaki Catchment was selected as the study area for the uplands case study. As the study area contains a good balance of general and specific resources, issues, and stakeholders, case study results would be relevant for understanding the potential impacts and implications of climate change to a broader spectrum of upland environments across New Zealand.

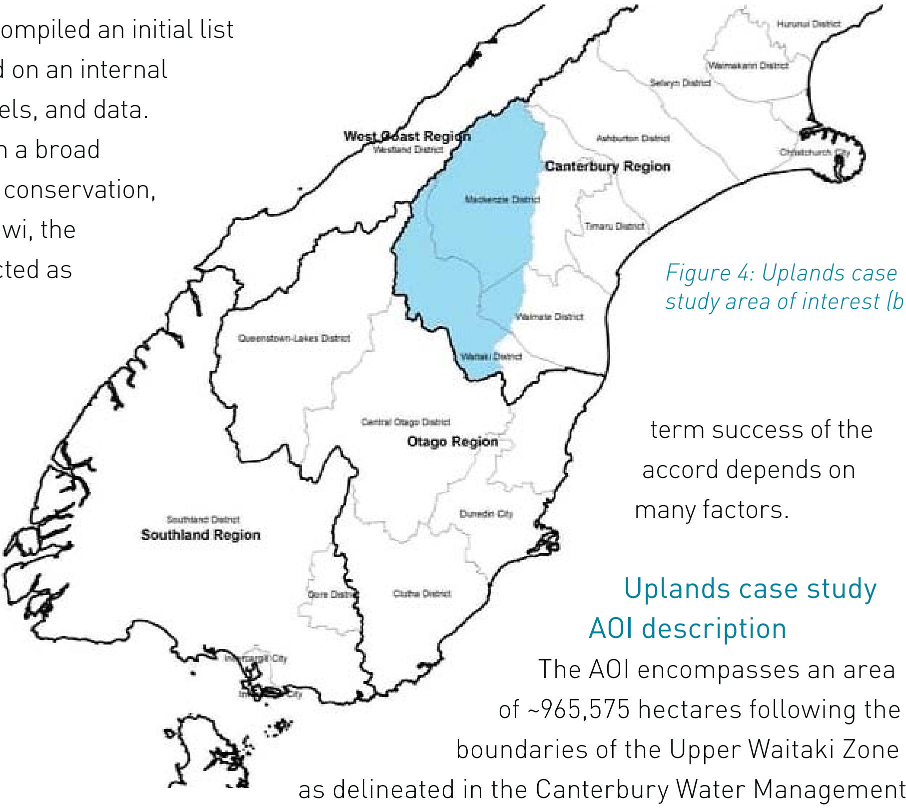

Figure 4: Uplands case study area of interest (blue).

The uplands case study area of interest (AOI) occurs within the southwestern portion of the Canterbury region and is adjacent to both the Otago and West Coast regions (Fig. 4). The AOI straddles three districts: Mackenzie, Waimate, and Waitaki. Key towns and settlements include Timaru, Lake Tekapo, Lake Pukaki, Mount Cook, and Otematata.

The AOI was selected because of its high public interest, significant pastoral and agricultural use, and high scenic and biodiversity values. The study area is subject to some significant tensions between farming and conservation interests, with extensive pastoral systems, and increased irrigation and intensification of some areas. For example, in 2017, an Environment Court judge reported that there is a strong case for an "immediate moratorium" on freeholding parts of the Mackenzie Basin, due to the rapid rate of ecological values being lost (NewsJS 2017). There are a number of large pastoral leases currently under Tenure Review. The recent Mackenzie Accord aims to resolve some of the intensification and conservation issues, but the long-term success of the accord depends on many factors.

Uplands case study AOI description

The AOI encompasses an area of ~965,575 hectares following the boundaries of the Upper Waitaki Zone as delineated in the Canterbury Water Management Strategy of the Canterbury Regional Council (Fig. 5).[1] Topographically, it is bordered on the north and west by the Southern Alps, including Mt D'Archaic, Mt Elie de Beaumont, Mt Tasman, Mt Cook, Mt Ward, and Mt Huxley, on the south by the Hawkdun and St Mary's Ranges, and in the east by the Kirkliston and Two Thumbs Range and the Grampian Mountains.

The large elevational gradient (378 to >3000 metres above mean sea level) within the AOI produces strong orographic effects that induce a high west-to-east annual precipitation gradient ranging from ~12,000 mm in the Southern Alps to ~600 mm in lower areas. Associated annual discharge rates range spatially and seasonally from 130 to 10,000 mm. The combination of climatic and topographic conditions spurred the development of an extensive water storage and electricity generation infrastructure network that substantially altered the catchment's hydrology. That network includes six hydroelectric

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[1] http://ecan.govt.nz/get-involved/canterburywater/Pages/canterbury-water-zone-map.aspx

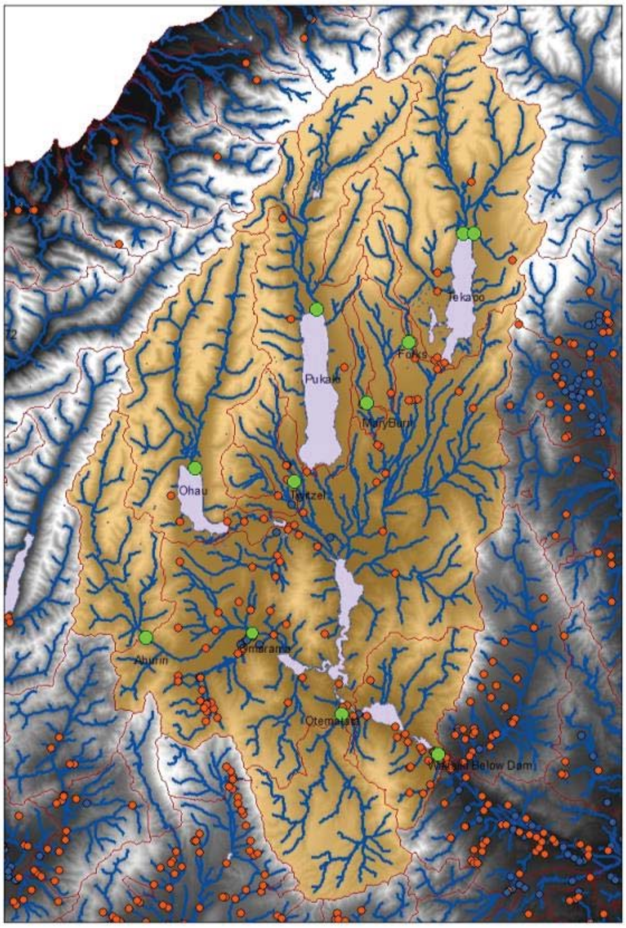


Figure 5: Upper Waitaki catchment river network including man-made reservoirs, consented surface water activities (● red dots), and locations for calibrating hydrological models, e.g. discharge at gauging station, lake inflows for lakes (● green dots).

reservoirs and associated dams: Lake Tekapo, Lake Pukaki, Lake Ohau, Lake Benmore, Lake Aviemore, and Lake Waitaki.

Catchment land cover is broadly separated into alpine and upland areas (Fig. 6). The northern area of the catchment encompasses a portion of the central Southern Alps and includes high-elevation environments such as snow and ice fields (glaciers) and alpine and sub-alpine ecosystems. Grasslands, which comprise 63% of total catchment area, dominate upland areas. Remaining land covers such as indigenous forest, urban, exotic forest, etc. comprise the remaining ~7% of the catchment, which represents a much lower total then their collective coverage nationally.

Land use in the catchment is predominantly divided between primary production and protected areas (Fig. 7), with hydropower generation also being extremely important given the substantial network of reservoirs and hydro dams.

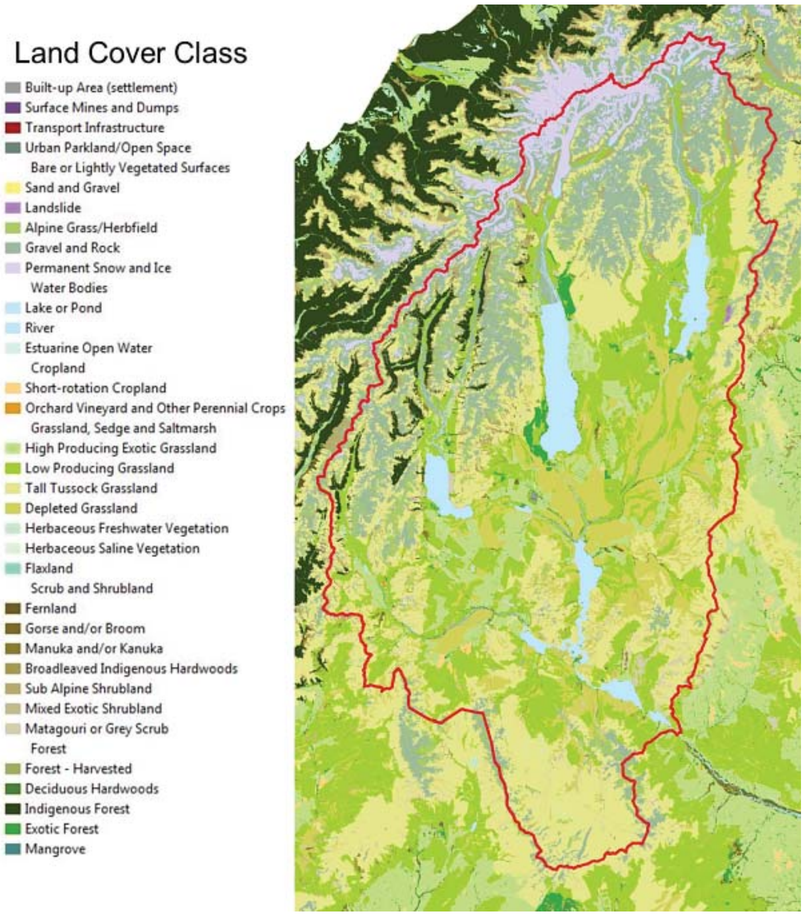
Overall primary production covers ~600,000 ha in the catchment (Fig. 7). The dominant farming types are sheep and beef (374,000 ha) and sheep farming (160,000 ha), reflecting available land use capability (Fig. 8). Numbers and areas of other farm types were much lower. As of 2014 the catchment had 1 dairy farm, 2 deer farms, and 1 vineyard. However, both sheep and sheep & beef farming showed a tendency towards multiple uses considering the diversity of livestock and other farming activities reported. Based on LINZ data (current as of 2013), a large proportion of farms are pastoral leases on Crown land.

Public conservation land, managed mostly by the Department of Conservation, occupies about 21% in the north and west of the AOI. Several national parks, conservation parks, and stewardship areas comprise the majority of protected areas and generally occur along the northern, western, and southern perimeter of the catchments. There are also numerous but smaller scenic reserves, recreation reserves, local purpose reserves, etc. The Tekapo Military Training Area (~14,500 ha) occurs just west of Lake Tekapo.

Given the iconic and outstanding landscapes, scenic amenity, and recreational opportunities, tourism is an important activity in the AOI, including several ski fields (Fig. 9). In addition to protecting important, representative areas for ecosystem and species conservation, conservation land also provides recreational opportunities including walking, tramping, mountain biking, and wildlife viewing.

Urban land uses occupy ~0.1% of the AOI and occur primarily around the major reservoirs, e.g. Timaru. The AOI includes 39 lifestyle blocks that occupy 129 ha of land in total.

Figure 6: Uplands case study AOI distribution of land cover in 2012. Based on the Land Cover Database (LCDB) Version 4.1.



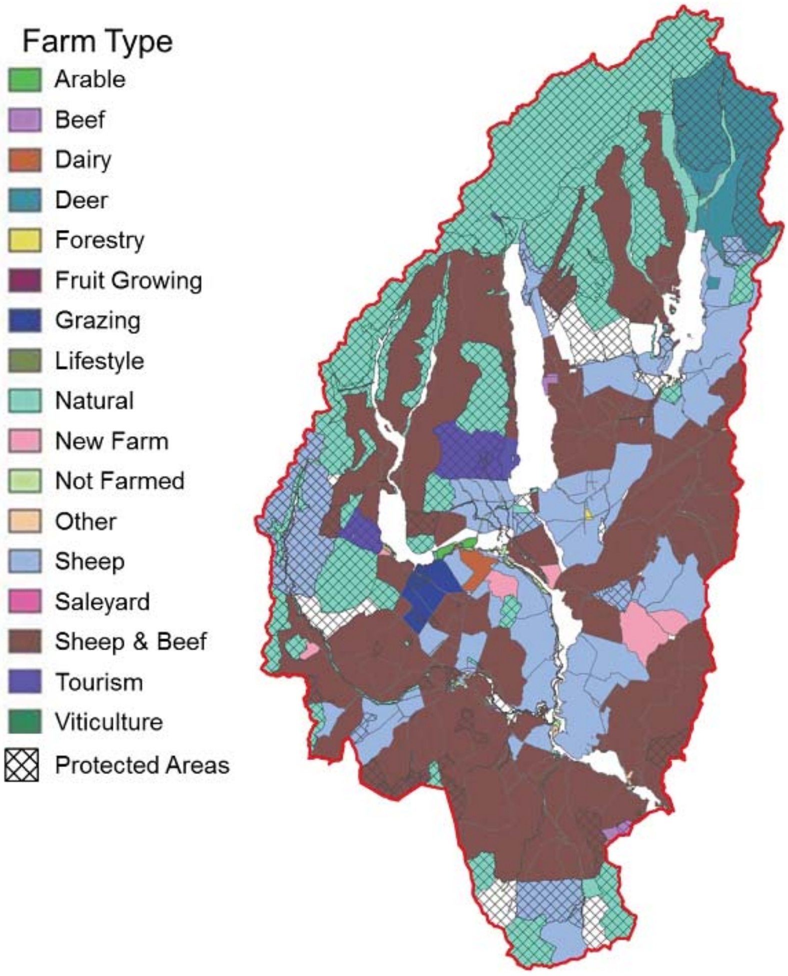


Figure 7: Uplands case study AOI 2014 land use. Based on AgriBase 2014 licensed for research purposes to Landcare Research by AssureQuality and PAN-NZ 2014 (Rutledge 2016).

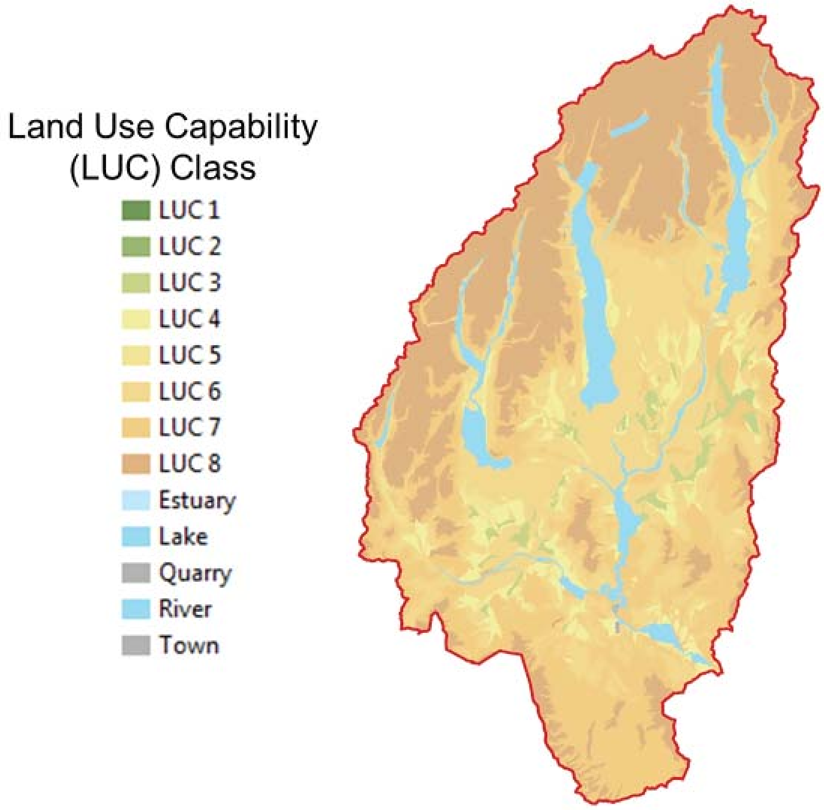


Figure 8: Uplands case study AOI distribution of land use capability. Based on Land Resource Inventory (LRI) Version 2.

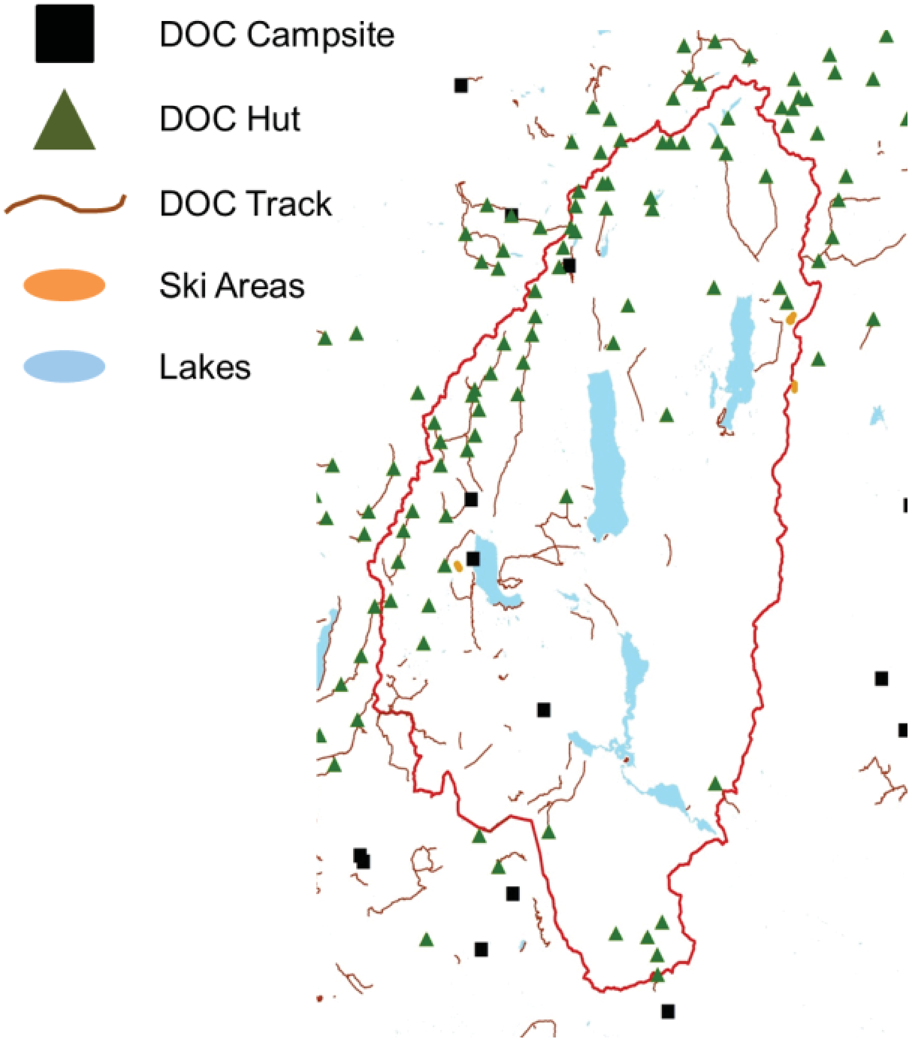


Figure 9: Uplands case study AOI key recreation and tourism assets. Based on spatial data from Land Information New Zealand Data Service available at https://data.linz.govt.nz/.

Key Stakeholders Issues

After the uplands case study AOI selection, more detailed discussions occurred with a broad range of stakeholders, facilitated with the assistance of Environment Canterbury staff and the Upper Waitaki Zone Committee, to identify potential key issues to address. In November 2014 a workshop sponsored by the Zone Committee was held in Twizel in which a range of stakeholders came together to discuss and share their perspectives and needs regarding potentially important impacts and implications of climate change (Table 1).

In October 2016 a second local workshop was held in cooperation with the Zone Committee to present the results of the uplands case study to interested stakeholders.

Table 1: Key themes and climate-related issues in the upper Waitaki catchment identified by stakeholders

Theme	**Climate-Related Issues**
Biodiversity & Conservation Management	
Braided rivers provide a patchwork of habitats (riffle, run, and pool sequences) supporting a diverse range of species and their different lifecycle stages. Riffles are also highly productive and important feeding habitats for fish and birds. River gravels are important nesting sites for native birds such as wry bills. Braided rivers also help maintain water quality via aeration and temperature regulation.	• Changing run-off (increased peak flows, higher erosion and deposition) and more dynamic morphology may disrupt habitats for many species, such as nesting sites for the endangered blue duck. • Warmer temperatures and higher snowline have implications for weed & pest management.
Livelihoods	
Agriculture is both a significant contributor to the local economy and an important way of life for many residents. Tourism is a significant economic driver and second only to hydroelectric power generation and agriculture.	• Amenity/scenic values and access challenges. • Snowmaking requires temperatures below freezing. Climate change may reduce the ability to substitute man-made snow if temperatures increase and/or snowfall decreases overall. • Milder and more variable temperatures impact the quality and value of merino wool and implications for the profitability and viability of the merino wool industry.
Power Generation	
The suite of hydroelectric lakes and dams in the upper Waitaki catchment collectively makes a significant contribution to national electricity generation and energy security. Hydroelectric generation is also a major sector of the local economy.	• High-winds can cause dam spill over, and damage structures. • Seiches – waves in enclosed bodies of water – may become more problematic if wind-speeds increase and can increase the stress on existing dams that may need to be upgraded to withstand greater pressure. • Other implications for hydro-generators include managing changes in seasonality – early or later peak run-off– and matching with changing demand (i.e. longer/shorter summers/winters). • Changing runoff regimes may have implications for consents, and any increased demand from agriculture for irrigation and groundwater recharge.
Wilding Conifers	
Wilding conifers are already a significant problem where they have invaded in large numbers. Problem species include: *Pinus contorta* (lodgepole pine), *Pinus nigra* (Corsican pine), *Larix decidua* (European larch), *Pseudotsuga menziesii* (Douglas fir), and *Pinus ponderosa* (ponderosa pine). Control currently occurs on a 6- to 8-year cycle.	• Increased rates of growth and spread. • Increased range above the current limit of ~1,300 metres above mean sea level. • Need for more frequent, extensive, and intensive management and control with implication for control costs. • Changes to wildfire risk profiles via, for example, generation of increased fuel loads.

METHODOLOGY

Overview

The uplands case study team attempted to evaluate the six CCII scenarios using a loosely coupled systems model consisting of an integrated suite of climate, economic, hydrology, primary productivity, pest, and rural land-use change models (Table 2; Fig. 10). The models were selected given their relevance to the key issues and impacts identified by stakeholders during case study selection (Table 1).

Table 2: Quantitative models used for the Uplands case study organised following the systems model diagram (Figure 10) first climatically by following links from global scenarios to the right via RCPs and second socioeconomically by following links from global scenarios down via SSPs & SPAs

Theme	Model	Relevant Indicator(s)
	Climate Perspective (via RCPs)	
Improved Climate Projections	New Zealand Regional Climate Model	Air temperature – maximum Air temperature – minimum Precipitation Relative humidity Solar radiation Sea level pressure Wind speed
Pasture Productivity	Biome-BGC	Pasture yield change
Hydrology & Water Resources	TopNet	Water discharge
Pests	CLIMEX	Pest suitability indices
Wilding Conifers	Wilding Conifer Spread Model & Wildfire Risk Model	Wilding conifer spread & dominance
	Socioeconomic Perspective (via SSPs, SPAs, and SPANZs)	
Global-New Zealand Socioeconomic Co-development	CLiMAT-DGE	Global commodity prices
Rural Land Use	LURNZ	Land use area change Land use spatial distribution

Quantitative models

Below, we overview the suite of models that comprise the uplands case study loosely coupled systems model. We discuss the models following the systems structure shown in Figure 10, first from a climatic perspective and then from a socioeconomic perspective.

Improved Climate Projections – New Zealand Regional Climate Model

RA1 used the New Zealand Regional Climate Model (NZ-RCM) to produce improved climate projections to 2100 that covered all of New Zealand including the uplands case AOI. Below is a brief overview of RA1 methods for ease of reference.
For more detail, consult the RA1 synthesis report (Tait et al. 2016).

Global climate modelling carried out for the IPCC 5th Assessment (IPCC 2014) served as the basis for the improved New Zealand climate projections (Fig. 10).

Global climate modelling teams used historic and future (i.e. the four RCPs) GHG emission time series as inputs to global Earth System Models/Global Circulation Models. The global models produced simulated historic climate conditions and projected future climate conditions for each RCP, resulting in 5 output data sets (1 historic + 4 RCPs) from each global model.

The RA1 team evaluated the suite of global modelling outputs to determine which global models best simulated historic climate conditions for New Zealand. Based on the evaluation, the RA1 team selected outputs from six global climate models as inputs to the New Zealand Regional Climate Model (NZ-RCM) (Mullan et al. 2013a,b) to generate improved higher resolution climate projections for New Zealand. Global model outputs provided both boundary and starting conditions for running the finer-scale NZ-RCM.

Table 3 and Table 4 summarise the direct RA1 improved climate projection outputs. The RA1 team also provided additional derived outputs (e.g. annual values, potential evapotranspiration) as needed by particular models in CCII.

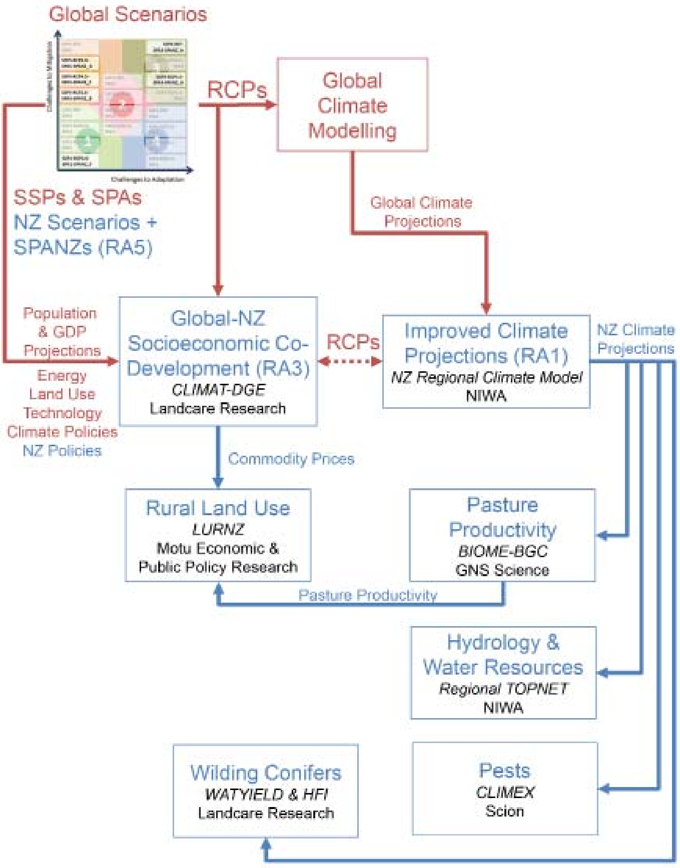


Figure 10: Uplands case study systems model showing New Zealand model components (blue boxes) and links (blue arrows) and global scenarios and models (red boxes) and links (red arrows).

Table 3: Specifications of improved New Zealand climate projections data produced by RA1

Specification	Detail
Spatial Extent	New Zealand Main & Inshore Islands
Spatial Resolution	0.05° x 0.05° or ~5 km x 5 km corresponding to the NZ Virtual Climate Station Network (VCSN)
Temporal Extent	Historic: 1979 to 2005 Projected: 2006 to 2100 or 2120 (varies by global climate model)
Temporal Resolution	Daily

Table 4: Climate variables produced by NZ-RCM

Climate Variable	Units
Maximum Air Temperature	degrees kelvin = °K
Minimum Air Temperature	degrees kelvin = °K
Precipitation (total)	millimetres = mm
Average Solar Radiation	mega joules per meter squared = MJ/m^2
Average Wind Speed at 10 m height	metres per second = m/s
Average Mean Sea Level Pressure	hectopascals = hPa
Average Relative Humidity	percent = %

Pasture productivity – Biome-BGC

The Biome-BGC model v4.2 (Thornton et al. 2002, 2005) is an ecosystem process model that simulates the biological and physical processes controlling fluxes of carbon, nitrogen and water in vegetation and soil in terrestrial ecosystems (Fig. 11). It includes CO_2 fertilization effects, which enhance the rate of photosynthesis and reduce water loss in plants under elevated CO_2 atmospheric concentrations.

Biome-BGC was adapted to model pasture productivity for two types of New Zealand managed grassland systems: sheep/beef (low intensity) and dairy (high intensity). Model parameters were calibrated against New Zealand pasture growth data (Fig. 12), including using the in-built C3 grasslands mode with some key ecological parameters modified and reinterpreted to represent managed pasture and the presence of grazing animals (Keller et al. 2014).

Unique parameterizations were developed for both sheep/beef and dairy farm systems. The main difference between them is the intensity of farming: dairy systems receive more nitrogen inputs to simulate more fertiliser use, more grass is eaten in the form of increased whole-plant mortality, and more animal products (milk or meat) are extracted from the system. In addition, the dairy parameterization effectively results in increased water-use efficiency. Note that irrigation is not simulated in either system.

Biome-BGC was run for each 0.05° x 0.05° grid cell in the AOI with location-specific weather inputs, soil texture and rooting depth (Table 5). Baseline pasture production was simulated using the RCP past climate input (representative of modern day conditions) and averaged over the period 1985–2005. For all future scenarios, the model was first spun up using RCP past climate, and then restarted and run as a transient simulation from 2005 to 2100.

Table 5: Summary of BIOME-BGC implementation for the Uplands case study (see also Fig. 12)

General	• 3820 sub-catchments with a mean area of ~7 km2
Assumptions	• Static land cover over simulation period No change in vegetation • Spatially and temporally constant nitrogen (fertilizer) inputs • No irrigation
Inputs	• Daily Minimum Air Temperature • Daily Maximum Air Temperature • Daily Precipitation • Daily Vapour Pressure Deficit • Daily Solar Radiation • Soil Texture • Elevation • Latitude • Atmospheric CO2 concentration
Outputs	• Daily net primary productivity (NPP) converted to above ground pasture growth

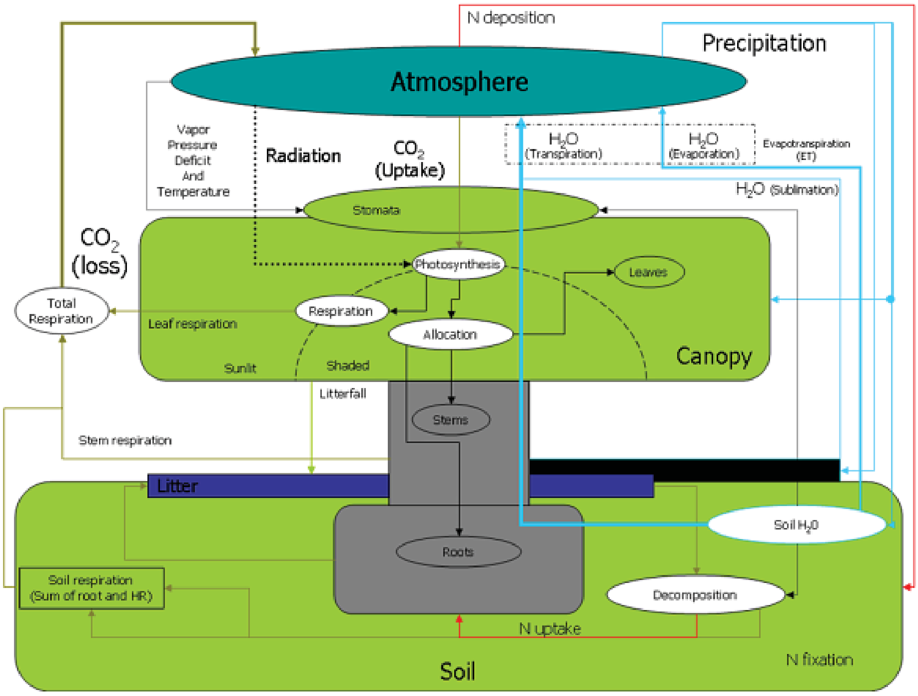


Figure 11: The Biome-BGC Model (BioGeochemical Cycles): A simulation of the biological and physical processes controlling carbon, water, and nitrogen dynamics in terrestrial ecosystems. Figure by the University of Montana's Numerical Terradynamic Simulation Group: http://www.ntsg.umt.edu/project/biome-bgc

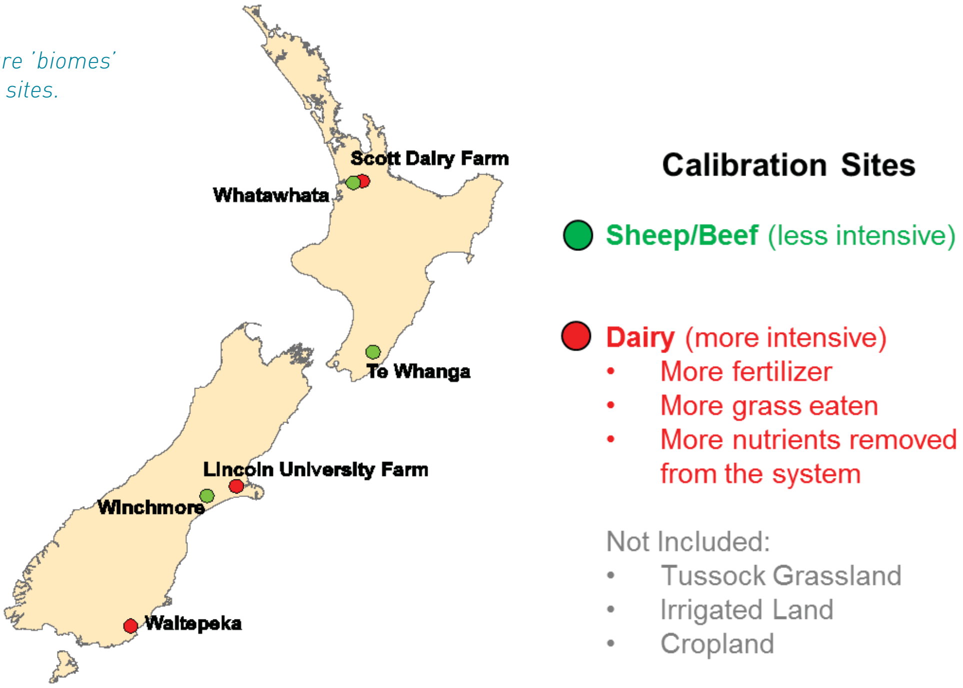


Figure 12: New Zealand pasture 'biomes' ~2005–2010 target calibration sites.

Hydrology & water resources – TopNet

Hydrology and water resources were modelled using TopNet (Clark et al. 2008), which is routinely used for surface water hydrological modelling applications in New Zealand (Fig. 13; Table 6). TopNet is a spatially semi-distributed, time-stepping model of water balance that is driven by time-series of precipitation and temperature, and of additional weather elements where available.

TopNet simulates water storage in the snowpack, plant canopy, rooting zone, shallow subsurface, lakes and rivers. It produces time-series of modelled river flow (without consideration of water abstraction, impoundments or discharges) throughout the modelled river network, as well as evapotranspiration, and does not consider irrigation. TopNet has two major components: a basin module and a flow routing module.

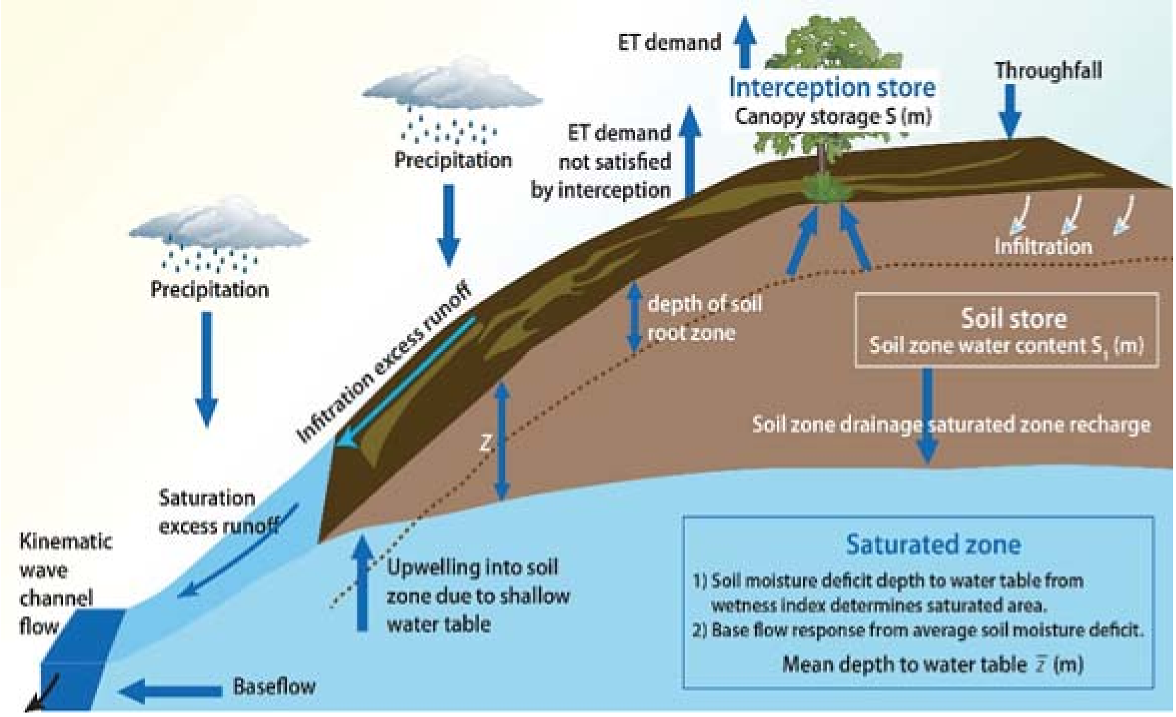


Figure 13: Conceptual diagram of the TopNet hydrological model.

Table 6: Summary of TopNet implementation in the uplands case study

General	• 3820 sub-catchments with a mean area of ~7 km^2 • 44 lakes • 10 calibration locations
Assumptions	• Static land cover over simulation period No change in vegetation characteristics • Hydrolakes modelled as natural lakes without consideration of any storage management for electricity generation purposes • Simple surface water/groundwater interactions
Inputs	• Air Temperature • Precipitation • Solar Radiation • Relative Humidity • Mean Sea Level Pressure • Wind Speed
Outputs	• Catchment discharge • Catchment runoff fluxes (Saturation excess, Infiltration excess, Groundwater discharge to stream) • Snow (accumulation, melt) per elevation bin • Catchment-scale soil moisture, groundwater recharge • Catchment-scale depth to groundwater • Vegetation characteristics (canopy storage, evaporation) • Lake (inflow, outflows, volume, surface area) • Catchment average or upstream catchment average fluxes at specific locations • Additional Analyses: ° Mean Annual Flow, ° Mean Seasonal Flows, ° Mean Annual Flood, ° Preliminary analysis for change in extremes (Mean Annual low flows, Maximum Annual Floods)

Pests – CLIMEX

New Zealand's economy is heavily reliant on primary production generating 65% of our export earnings by exploiting introduced plants and animals. Biosecurity is of critical importance to protect the production system as New Zealand's climate is highly suitable for both the species in use and the pests and diseases that impact on them. Equally important is the threat and impact that unwanted pests could have on New Zealand's native and endemic plants and animals (Kean et al. 2015). The Parliamentary Commissioner for the Environment has stated that 'Introduced pests are the greatest threat by far to New Zealand's native plants and animals' (PCE 2011).

Climate is one of the major factors limiting the distribution of plants and cold-blooded animals, hence changes in climate and climate distribution is expected to amplify the risk and impacts of pests being able to establish populations in New Zealand, with larger areas being more suitable for the establishment of current and known pests as well as becoming attractive to pests that are not currently able to establish populations in New Zealand. Climate change also increases the risk associated with 'sleeper' weeds, the > 30,000 plants that are in gardens that could become more invasive threatening indigenous and productive ecosystems (Kean et al. 2015).

Climex (Kriticos et al. 2015) is a mechanistic species distribution model that identifies potential changes to habitat suitability for a species by comparing its current climatic range based on documented observations to its potential future range under a changing climate. Climex uses 1) average maximum air temperature, 2) average minimum air temperatures, 3) precipitation, and 4) relative humidity.

A range of indices predict growth and indices that assess limiting conditions such as the survivability of periods of extreme cold, heat, wetness or drought, and combinations of these stresses, e.g. hot and wet, cold and wet (stress indices). These indices are combined into an Eco-climatic Index (EI), an overall measure of the potential of a given location to support a permanent population. EI is scaled between 0 and 100, with an EI close to 0, indicating that the location is not favourable for the long-term survival of the species. Hence, Climex enables the ability to project relative abundance and distribution of modelled species anywhere in the world (Sutherst & Maywald 1985, 2005; Baker et al. 2011; Kriticos et al. 2015).

For the uplands case study, Climex models were provided by (Agresearch) via the Climenz website, as Climex-ready parameter files, saving considerable time as well as ensuring parameter accuracy. Climex modelling was limited to species where there was an existing Climex model on the Climenz website[2] and where the model did not contain any parameter inconsistencies. No new models were developed. This updates some of the models that have been run using earlier climate change projections.

Species modelled were selected from a range of sources that identified pests or unwanted organisms in NZ, such as the NPPA, legal sources (notifiable organisms) and those recommend as pests either as have been modelled in NZ before using earlier climate data sets, or as potential threats to biodiversity or production systems.

For each of the pest species the following data were developed:

- Raster images of EI for each of the GCM X RCP X 5 year (c. 552 images/species)
- Raster images of EI for each GCM X RCP X three normal periods (2005, 2050, 2090) (72 images species)
- Raster images of MAX EI of RCP's, for each GCM X three normal periods (2005, 2050, 2090) (18 images/species)
- Raster time difference images of MAX EI of RCPs for each GCM (2005–2050, and 2005–2090)

Wilding Conifers – Wilding Conifer Spread Model & Wildfire Risk Model

Wilding conifers have invaded large areas of non-woody vegetation, particularly in the eastern rain shadow of the South Island including being a major problem in the upper Waitaki catchment (Fig. 14). Conifers potentially reduce water yield by increasing both interception loss and transpiration. They also potentially increase wildlife hazard by generating large volumes of highly flammable fuel. Climate change may intensify impacts of conifers by exacerbating the decrease in water yield and increasing the risk of wildlife threat.

Two existing models were used to explore the potential impacts on water yield and wildlife threat: WATYIELD (Fahey et al. 2010) and the head fire intensity (HFI) model (Anderson et al. 2008). WATYIELD calculates the water yield at the bottom of a catchment based on land cover and soils, including soil water-holding capacity. HFI is the predicted intensity, or energy output, of the fire at the front or head of the fire measured in kilowatts per meter (kW/m). HFI is based on rate of spread and the total fuel consumption and is a standard gauge by which fire managers estimate the difficulty of controlling a fire and select appropriate suppression methods.[3]

Modelling involved comparing scenarios combining two realisations of land cover and three climate periods based on NZ-RCM output from the global Hadley (HadGEM2-ES) climate model under RCP8.5. The two land cover realisations were a 2014 baseline from LCDB4.1 and potential invasion of all invasion prone areas >10 degrees slope. The three climate periods were 1986–2005, 2046–2065, and 2081–2100.

For each combination of land cover x climate (2 x 3 = 6 in total), WATYIELD calculated catchment water yield using crop coefficients and interception fraction and loss specific to each land cover class. The HFI model estimated the 80th percentile for three cover types (forest, grassland, shrubland) assuming each land cover type covered the entire catchment. Each cover-specific was then clipped to the extent of the corresponding land cover class in the baseline or the invasion realization, and then the resulting composite map was used to calculate the mean HFI value across the entire catchment.

[2] http://b3.net.nz/climenz/index.php

[3] The Canadian Wildland Fire Information System web pages provide a useful overview of the HFI index (http://cwfis.cfs.nrcan.gc.ca/home)

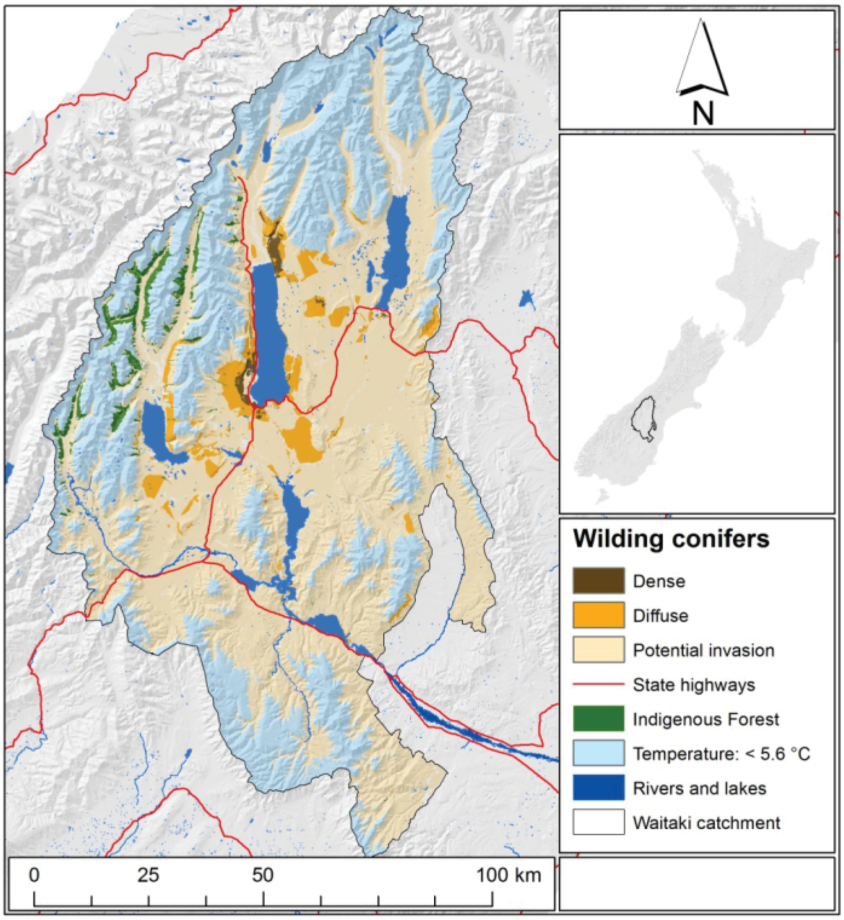


Figure 14: Estimated 2012 (dark brown and orange) and potential future distribution (tan) of wilding conifers in the uplands case study AOI.

Global-NZ Socioeconomic Co-development – CliMAT-DGE

We used the Climate and Trade Dynamic General Equilibrium (CliMAT-DGE) to assess global and New Zealand socioeconomic development under the six CCII scenarios. CliMAT-DGE is a multiregional, multi-sectoral, forward-looking dynamic general equilibrium model with a 100-year or longer time horizon (Fernandez & Daigneault 2015). This model was developed to study the efficient (re)allocation of resources within the economy and the response over time to resource or productivity shocks.

CliMAT-DGE produced projections of global commodity prices to 2100 that became inputs to rural land use modelling. For more information on CliMAT-DGE implementation within the CCII project, refer to the RA3 synthesis report (Rutledge et al. 2017).

Rural Land Use – LURNZ

The Land Use in Rural New Zealand (LURNZ) model is a spatially-explicit model of national land use (Timar 2011, 2016; Kerr et al. 2012; Kerr & Olssen 2012. LURNZ uses econometrically estimated functions that establish the relationship between observed drivers of land use and land-use change outcomes.

LURNZ requires relatively few assumptions about individual motivations of rural decision makers, which makes the model generally robust and transparent. On the other hand, its empirical foundation can also make the model less flexible and more prone to data limitations. For example, when future values of the explanatory variables exceed their historical range, LURNZ simulations results should be interpreted carefully.

LURNZ evaluations were limited to the Unspecific Pacific scenario (Fig. 3). LURNZ simulations were designed to try to disentangle the effects of climate and economic drivers (Table 7). Four sets of mid-century and end-of-century simulations were performed using the 25-hectare version of LURNZ:

1. “Baseline” runs use Situation and Outlook for Primary Industries (SOPI) 2015 commodity price projections through 2020 and constant prices thereafter and serve as the reference against which other simulations can be evaluated.

2. “Price only” runs hold climate parameters at baseline values and allow commodity prices are to change. Specifically, these runs are based on commodity price projections to 2100 generated by CLiMAT-DGE model under SSP3 assumptions.

3. “Yield only” runs hold prices at their baseline values. Pasture productivity changes based on spatially explicit projected changes from Biome-BGC. LURNZ cannot yet implement changes in forestry yields spatially, so here we apply the projected proportional increase in yields from the CCII Lowlands case study modelling (Ausseil et al. 2016).

4. “Combined” runs allow both price and productivity to vary. The two effects are approximately additive at the national level but not necessarily at other spatial scales.

Table 7: Summary of LURNZ implementation in the uplands case study

General	Five land uses: Dairy, Forestry, Horticulture, Scrub, Sheep & Beef ~100,000 hectares or 11% of catchment modelled (Fig. 15)
Assumptions	Modelled changes in mean climate only No adaptations other than land-use change Irrigation (actual or potential) is not modelled
Inputs	Commodity prices (from CliMAT-DGE results from RA3 based on SSP3) Pasture productivity (from BIOME-GBC based on RCP8.5) Base land use (2012) Econometric parameterisations from historic observations
Outputs	Land-use area Land-use spatial distribution

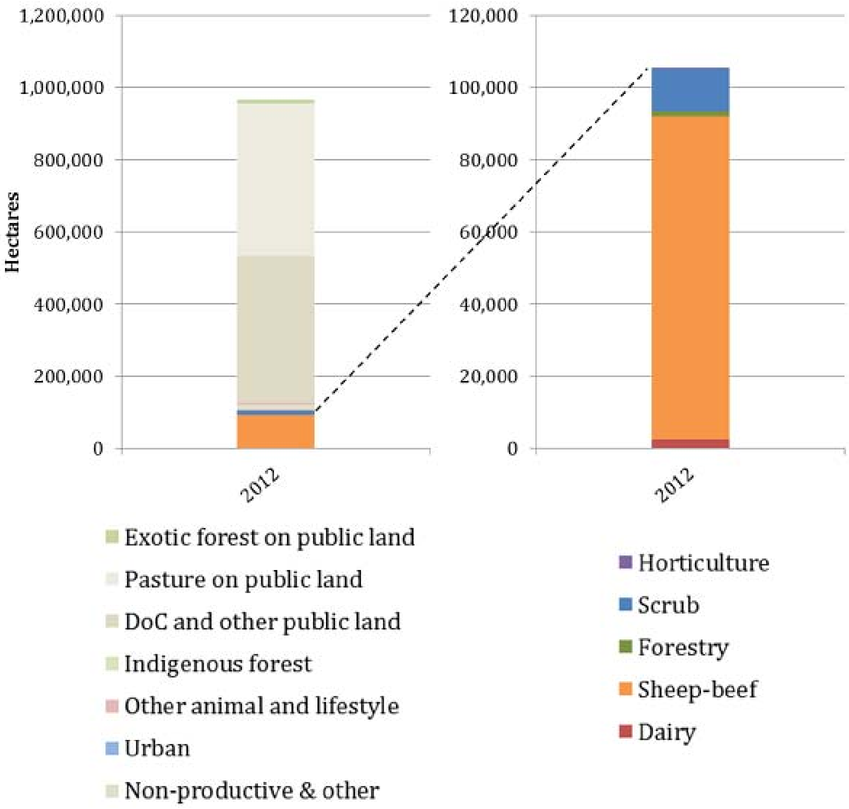


Figure 15: Area modelled by LURNZ for the uplands case study AOI.

RESULTS AND DISCUSSION

In this section we present modelling results ordered as before following the structure of the uplands loosely-coupled systems model (Fig. 10) first from a climate (RCP) and then socioeconomic (SSP) perspective.

Improved climate projections – New Zealand Regional Climate Model

NIWA completed a national assessment of updated climate change projections for New Zealand based on data described in the CCII RA1 Synthesis Report for the Ministry for the Environment (MfE 2016).[4] For this report we provide a snapshot of the results for the Canterbury region and, by extension, for the Uplands case study AOI.

Impacts

Overall improved climate projections indicate that the climate in the Canterbury region would become warmer and more variable. Under RCP8.5, the regional climate in 2100 compared with present day shows mean seasonal air temperatures increasing from 2.6 to 3.3 °C, mean seasonal precipitation increasing (except autumn) although with more dry days and increased likelihood of water stress, more hot days, fewer cold nights, and increased magnitude and variability (Table 8). Increasingly stringent mitigation targets and lower RCPs (e.g. RCP6.0 to RCP4.5 to RCP2.6) would show trends with decreasing magnitudes but equivalent range of variability.

Table 8: Overview of future changes to Canterbury regional climate in 2100 under RCP8.5

Climate Indicator	**Unit**	**Trend**	**Projected Change(s)**			
Mean Seasonal Air Temperate	°C	↑	Spring Autumn	+2.6 +3.0	Summer Winter	+3.0 +3.3
Change in Mean Seasonal Precipitation (at Tekapo)	%	↑	Spring Autumn	+13 –2	Summer Winter	+5 +28
Number of "Hot Days" with $T_{max} \geqslant 25$°C	days/year	↑	2006 (Present day) 2080–2099 (End of century)			27.3 62.3
Number of "Cold Nights" with $T_{min} \leqslant 0$°C	days/year	↓	2006 (Present day) 2080–2099 (End of century)			46.7 8.8
Number of "Dry Days" with Precipitation < 1mm/day	days/year	↑	+5–10			
99th Percentile Rainfall Amount (approximately equal to the heaviest 24-hour rainfall each year)	%	↑	+10–15			
99th Percentile Wind Speed (approximately equal to the third highest average daily wind speed each year)	%	↑	+5–10			
Potential Evapotranspiration Deficit (amount of water needed for irrigation)	mm/year	↑	+50–100 (approximately 25–35% increase from present-day)			

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[4] http://www.mfe.govt.nz/publications/climate-change/climate-change-projections-new-zealand

Implications

Climate in the upper Waikati catchment will become overall warmer and wetter. It will also become more variable as indicated by modelled increases in number of hot days, dry days, and heavy rainfall amounts. The degree of change will depend on the level of additional radiative forcing, i.e. RCP.

Taken together the modelled changes in key climate variables imply an increasing level of uncertainty, which implies a corresponding increase in climate-related risks and vulnerabilities.

Pasture Productivity – Biome-BGC

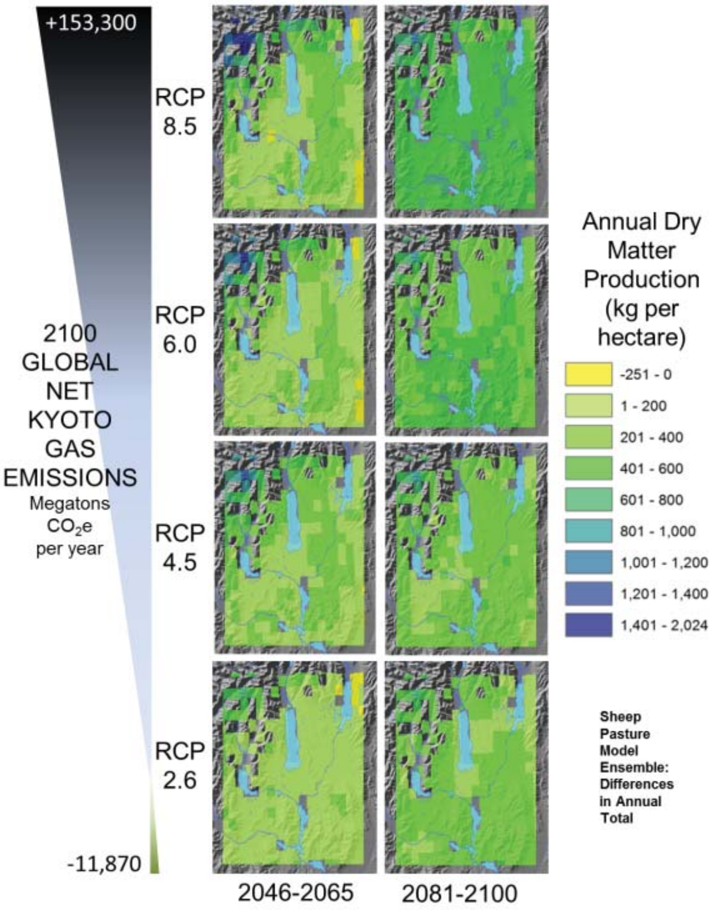
Impacts

Biome-BGC showed a trend of increasing annual pasture production over time with increasing net CO_2 emissions and RCP (Fig. 16), resulting from the larger positive effect of CO_2 fertilisation compared to negative effects of other aspects of climate change (e.g. increasing temperature). Application of nitrogen enhances the CO_2 fertilisation effect. If pasture systems are strongly nitrogen-limited, such as unimproved tussock grasslands, modelling results likely overestimate potential gains from CO_2 fertilisation. Broad annual increases masked more pronounced seasonal variation (Fig. 17). Pasture productivity increased most in winter, although small in absolute terms, and spring due to warmer temperatures and an extended growing season. That trend reversed to a relative decrease in summer, likely because of hotter, drier conditions, and then recovered to a small relative increase in autumn.

Implications

Emerging seasonal differences may necessitate adaptation to cope with the changing conditions. The more productive and warmer winters may reduce animal stress, allow for more winter grazing, and lead to better condition coming into the spring. Conversely, the combination of the relative decrease in the summer pasture productivity and increased temporal variability overall could generate more uncertainty in the frequency, timing, and severity of summer feed gaps. This increased uncertainty could increase farming risks and reduce profitability via, for example, increasing the need to hedge against feed gaps by producing or buying supplemental feed.

Figure 16: Future differences in total annual dry matter production at 2046–2065 and 2081–2100 compared with 1985–2006 modelled by Biome-BGC. The scaled bar at the left depicts the range of annual global net Kyoto gas emissions at 2100 from global integrated assessment modelling conducted as part of the IPCC's Fifth Assessment.



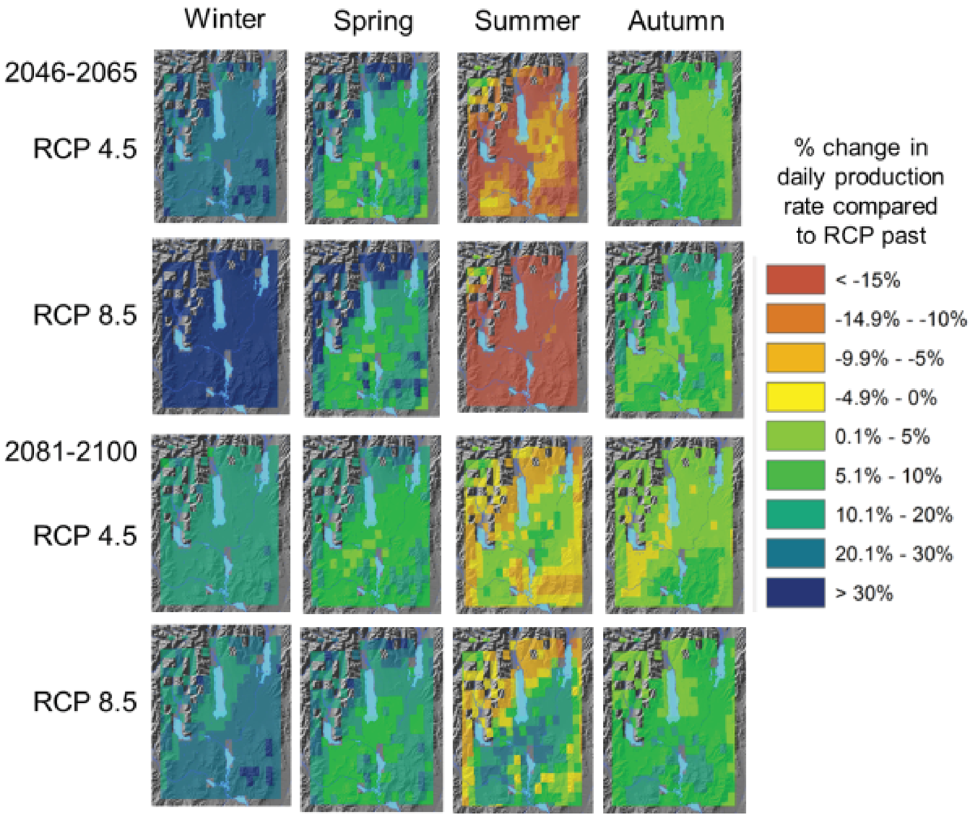


Figure 17: Future percent change in seasonal daily pasture production for the periods 2046–2065 and 2081–2100 compared with the baseline period (1985–2006) modelled by BIOME-BGC.

Hydrology & Water Resources – TopNet

TopNet is a data- and processing-intensive model. A single 20-year time slice run using NZ-RCM output requires 12 days of processing on a supercomputer cluster and produces ~160 GB of output. As a consequence, we present only a small subset of the results.

Impacts

Mean Annual Flows

Mean river discharges change in both space and time in response to shifts in precipitation patterns (Table 9; Fig. 18). Mean values show larger increases at higher elevations and by the end of the century, and larger decreases at lower elevations. Dispersion is also larger by the end of the century.

Seasonal Flows

Seasonal analysis indicates more nuanced/contrasted assessment (Table 9; Fig. 19). In winter, hydrological changes across headwater catchments vary. There are non-negligible changes even at low elevations and larger dispersion by the end of the century. In summer, discharges tend to decrease by the end of the century in headwaters but increase at lower elevations. Dispersion is also larger in the summer.

Overall seasonal changes are not linear, which has potentially large impacts for river ecology, water allocation and hydroelectric generation by the end of the century (Fig. 20). Hydro-electric generation potential is likely to increase by the end of the century for all the current hydrolakes. Conversely, more water could be stored for ecological release further in the summer months resulting in ecological values to be maintained or perhaps used to sustain agricultural activities across the catchment.

Table 9: Percent change in the median of mean annual and seasonal (summer, winter) discharge at Twizel and Omarama in the upper Waitaki catchment. Numbers in parentheses indicate the full range of values across all six improved New Zealand regional climate projections modelled by TopNet

	% Change in Discharge Compared with 1986–2005						
	2015–2035	2045–2065			2080–2099		
	Annual	Annual	Summer	Winter	Annual	Summer	Winter
Twizel	+5.7 [0.5 to +13.0]	+4.4 [−0.6 to +13.0]	−22 [−72 to −15]	−28 [−68 to +16]	+5.7 [−4.0 to +15.5]	−35 [-61 to +38]	−35 [−50 to +92]
Omarama	+13.0 [−2.5 to +15.0]	+7.0 [0.6 to +25.0]	−16 [−22 to +26]	−17 [−45 to +42]	+18.0 [−0.5 to +23.0]	−22 [−50 to +170]	−10 [−22 to +167]

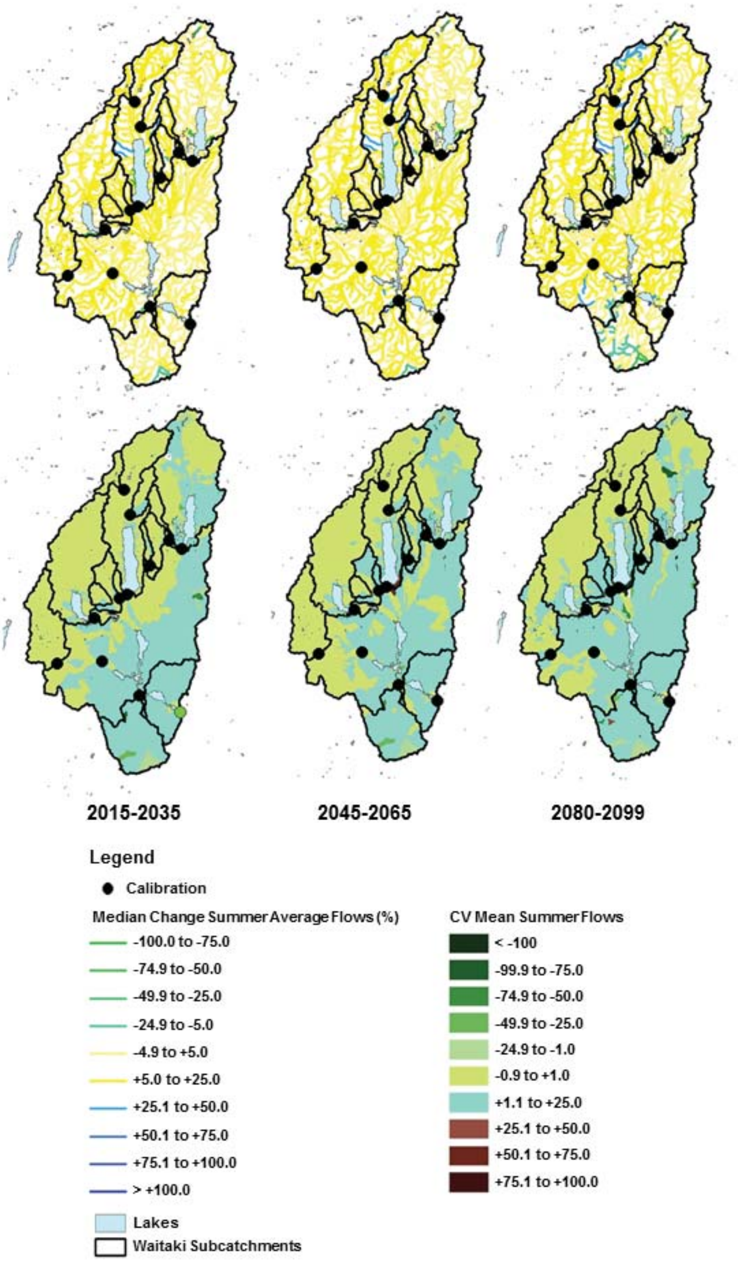


Figure 18: Future changes in mean average discharge (upper figures) and average dispersion (lower figures) in the upper Waitaki catchment for three time periods under RCP8.5 and the HadGEM model modelled by TopNet.

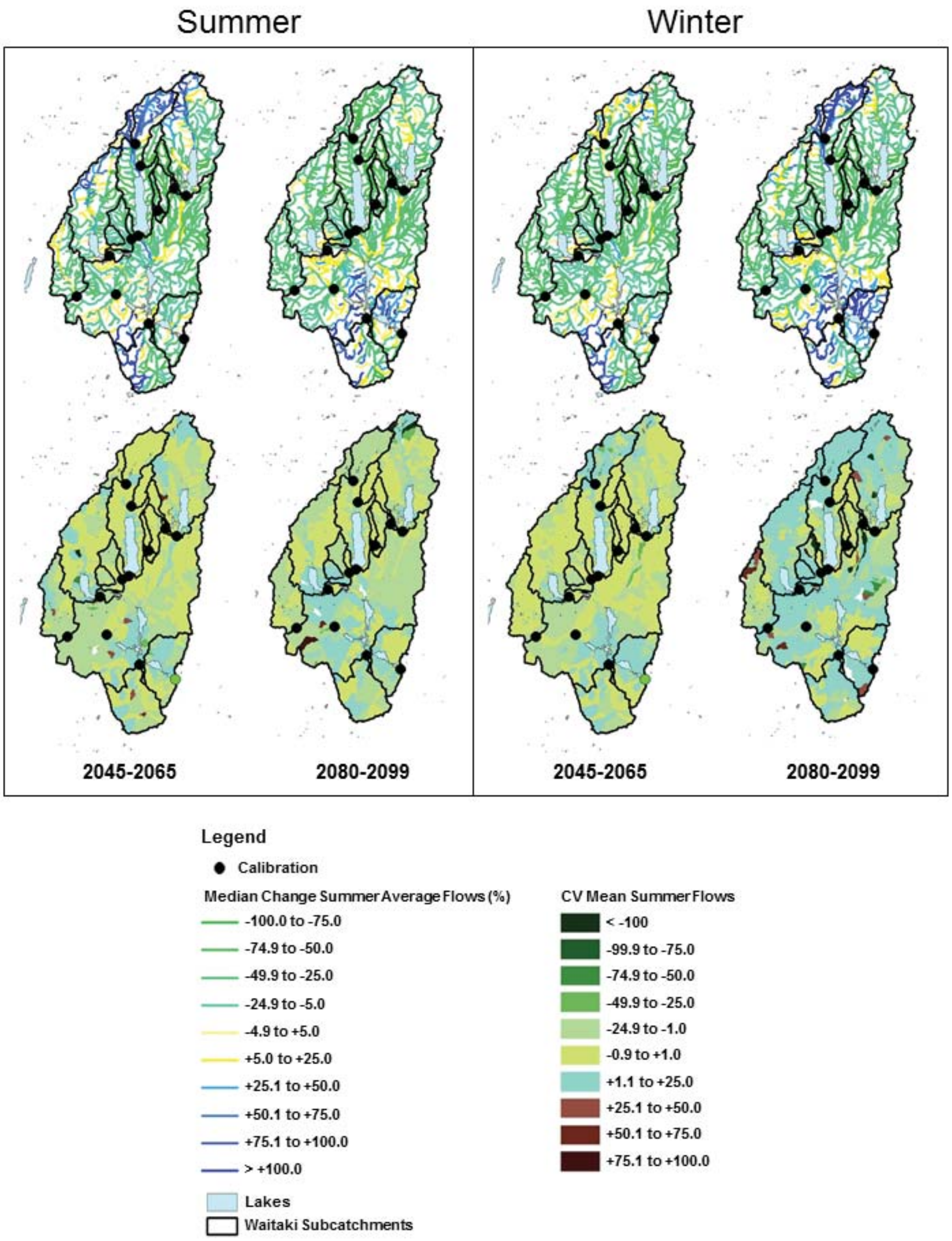


Figure 19: Future median changes in seasonal average flows in summer and winter in the upper Waitaki catchment for two time periods under RCP8.5 and the HadGEM model modelled by TopNet.

Implications

Overall climate change will increase the complexity of water management in the upper Waitaki catchment, making it more challenging to meet the range of needs across the system. The magnitude of the challenge will likely increase with increasing greenhouse gas emissions and resulting concentrations and radiative forcing, as represented by the family of four RCPs; however, determining trends from these changes (e.g. linear, non-linear) is difficult given the small ensemble of models available to evaluate.

The main driving force appears to be the changing dynamics of precipitation in terms of the spatial and temporal patterns and relationships among snow, ice, and rainfall. Overall total precipitation in the South Island including the Upper Waitaki catchment is likely to increase. The increase in total precipitation would tend to increase lake inflows, and the effect is expected to increase with increasing radiative forcing, i.e. higher RCPs.

However, other factors counterbalance that broad trend, including decreasing snow generation with

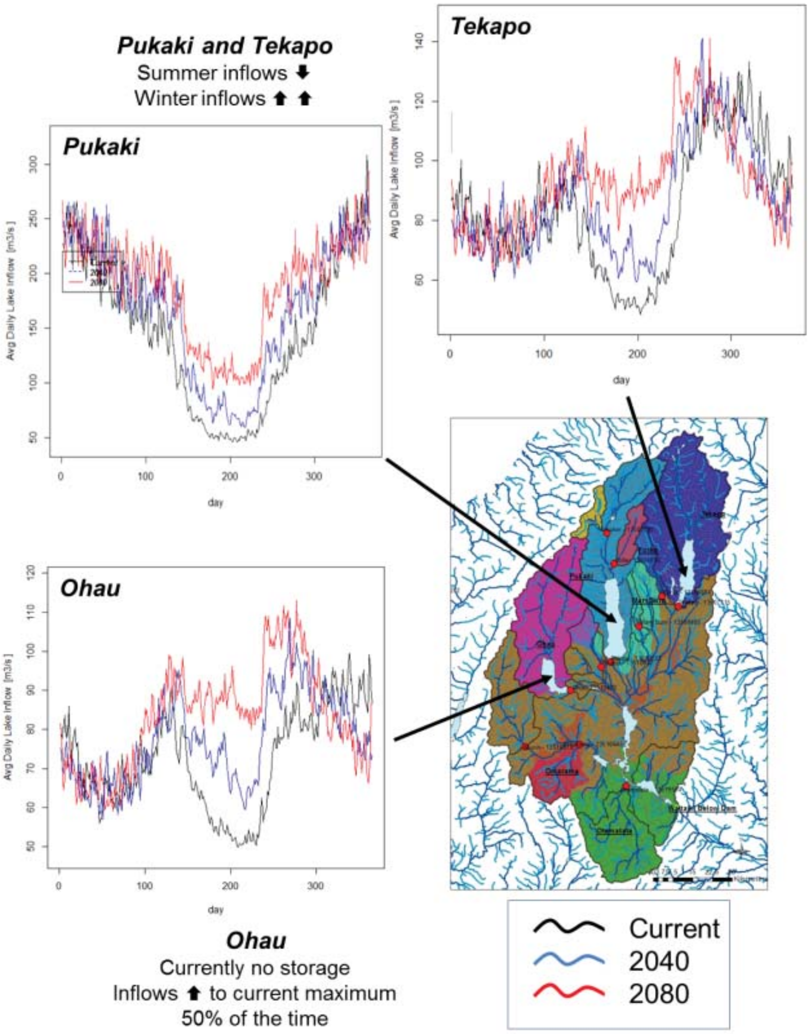


Figure 20: Modelled future changes in average daily lake inflow for three hydropower lakes in the Upper Waitaki catchment under RCP8.5 and the HadGEM model.

increasing climate change and increasing variability, both overall and seasonally, dependent upon the scenario and time period considered. As a result, mean annual flows showed small average changes, except in the headwaters of Lake Pukaki. Mean seasonal flows showed more pronounced differences, which has implications for managing water allocation and quality the diverse range of needs identified by stakeholders, e.g. habitat management in braided rivers, irrigation, electricity generation, etc.

Pests – CLIMEX

Impacts

Figures 21–23 show the progression of a selection of pest species in the uplands case study AOI. National maps (as pdfs) are also available via the CCII website (ccii.org.nz) and the Climate Cloud website (www.climatecloud.co.nz).

The Ecoclimatic Index (EI) is the maximum value from each of the six NZ-RCM runs and hence can be considered a worst case projection. EI is a climate index only. It does not include factors such as the incursion source or pathways and likelyhood, nor other non climatic factors that may enable or inhibit population establishment and survival such as host availability or the presence or absence of predators.

Groundsel Bush – **Baccharis halimfolia**

Groundsel bush is a serious weed of forestry, horticulture, cropping and grazing industries. It readily invades open to densely vegetated forests and agricultural land and reduces the productivity and carrying capacity of agricultural land by inhibiting the movement of livestock and causing livestock to lose condition rapidly if forced to graze it.

Groundsel bush is particularly invasive in some specific situations:

- badly-drained, poor, coastal wetlands
- areas where groundcover has been disturbed
- all grazing land that is overgrazed or under vegetated – newly-cleared land is prone to invasion, as is land which has suffered from fertility rundown and neglect
- open or poorly-developed forest areas after logging when canopy cover is reduced and soil disturbance is at a maximum
- occasionally, even in dense pasture.

Climate change decreases the potential distribution of groundsel bush, although the magnitude of the change varies depending on the magnitude of climate change (Fig. 21). Unsuitable areas increase primarily along the Southern Alps by 2050 compared with 2005. The increase continues to 2090 for RCP6.0, but reverses somewhat for RCP4.5, although the net gain in unsuitable area from 2005 to 2090 remains positive.

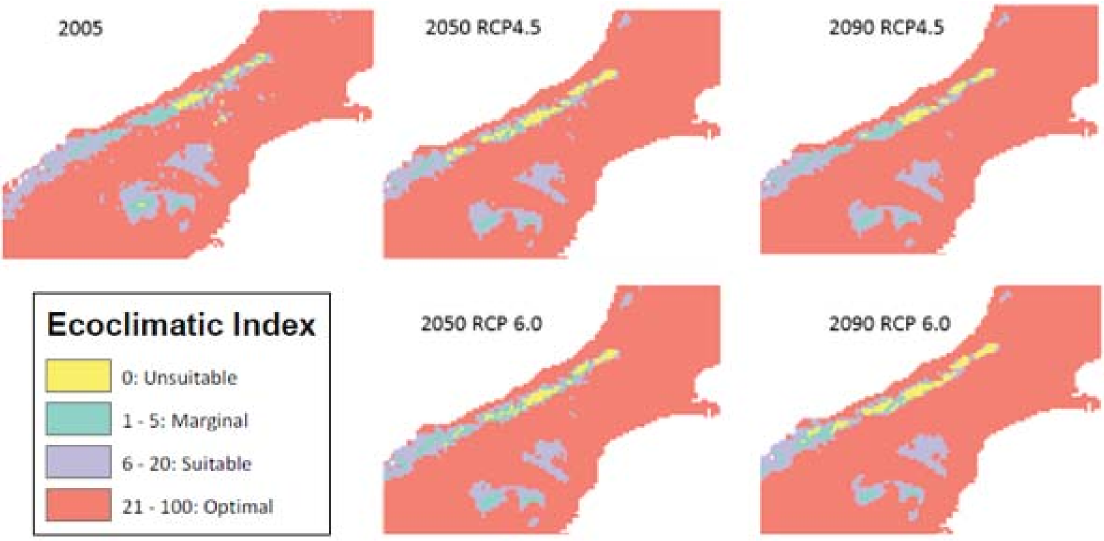


Figure 21: Maximum Ecoclimatic Index of Groundsel Bush (Baccharis halimfolia) *under RCP 4.5 and RCP6.0. The EI is the maximum estimated for each 5-km X 5-km pixel from six runs of the NZ-RCM based on results from six different global climate models.*

Old Man's Beard – **Clematis vitalba**

Old Man's Beard is a very serious environmental weed in New Zealand. It is a deciduous, fast-growing vine with the ability to climb and results in the collapse of trees, hence reducing standing forests to an impenetrable low-growing infestation of the vine, with all vegetation suppressed beneath. It is a strong colonizer of disturbed ground and the infestation can reduce the forest structure, and change the recruitment patterns in forests.

Climate change increases the potential distribution of old man's beard (Fig, 22). Unsuitable areas decrease and marginal, suitable and optimal areas increase under both RCP4.5 and RCP6.0, with the latter having more suitable and optimal area by 2090.

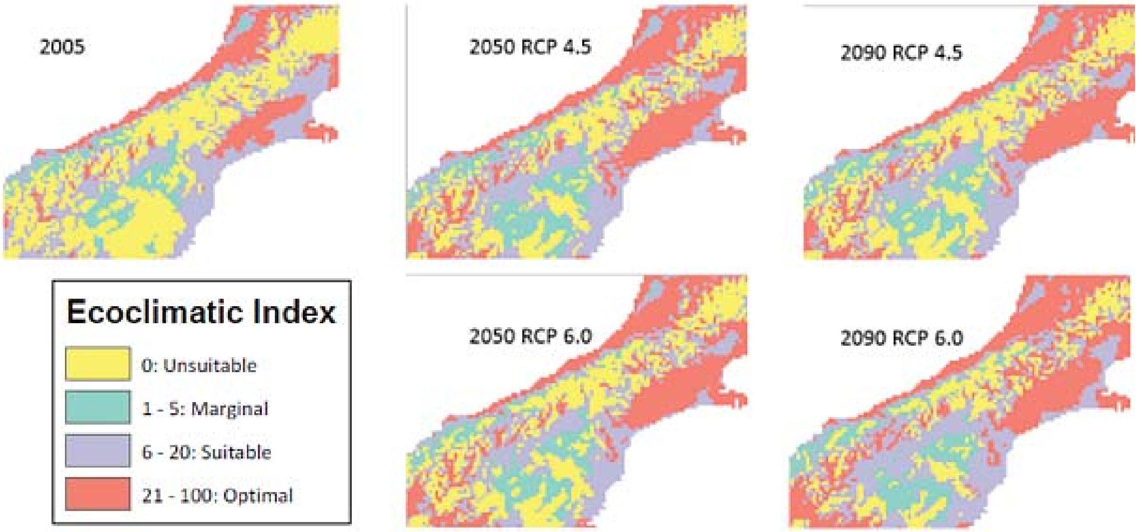


Figure 22: Maximum Ecoclimatic Index (EI) of Old Man's Beard (Clematis vitalba) *under RCP 4.5 and RCP6.0. The EI is the maximum estimated for each 5km X 5km pixel from six runs of the NZ-RCM based on results from six different global climate models.*

Buddleia – **Buddleja davidii**

Buddleia is a deciduous, open, multi-stemmed shrub that forms dense stands in a wide range of habitats. Buddleia is extremely ecologically versatile, tolerating a wide range of soils, especially poor soils, and frosts. Thickets establish and grow quickly, and are self-replacing. It is invasive as it reseeds into bare ground sites and cut stumps will also resprout.

Buddleia invades river beds, stream sides, disturbed forest, shrubland margins and bare land as well as being a major weed in radiata pine plantations where it can cause growth reduction and economic loss. In river beds, buddleia can modify water flow, enabling silt build up and flooding problems.

Climate change increases potential distribution of buddleia (Fig. 23). Unsuitable areas decrease and marginal, suitable and optimal areas increase under both RCP4.5 and RCP6.0, with the latter having more suitable and optimal area by 2090.

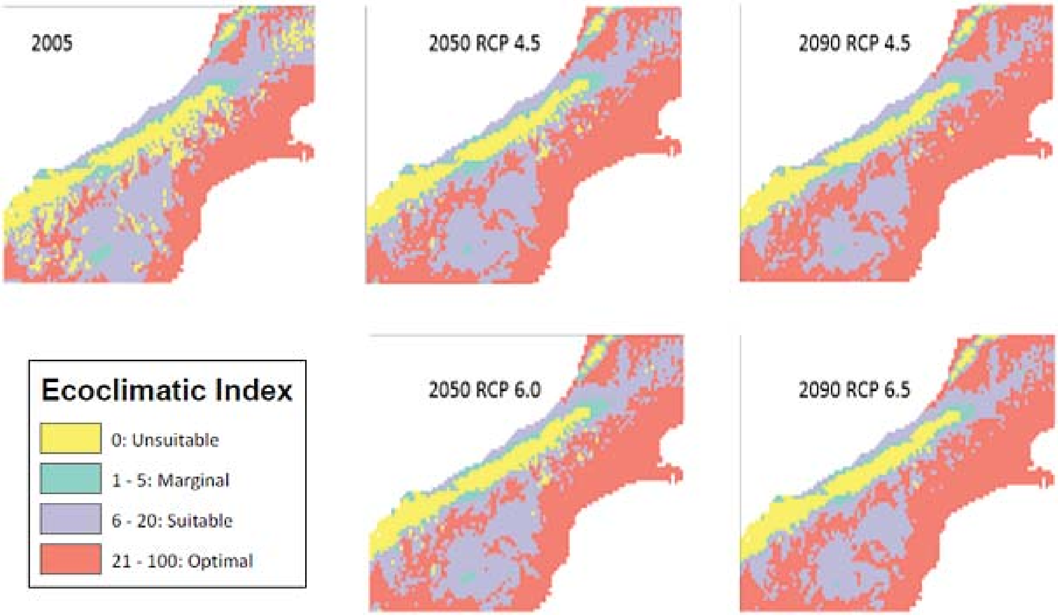


Figure 23: Maximum Ecoclimatic Index of buddleia (Buddleja davidii) *under RCP 4.5 and RCP6.0. The EI is the maximum estimated for each 5-km x 5-km pixel from six runs of the NZ-RCM based on results from six different global climate models.*

Implications

As the three examples have shown, climate change will have mixed implications for weed distribution and management in New Zealand. Potential distribution of two of the three weed species modelled increased, and one decreased. Full understanding of the potential implications for weed impacts and management will require detailed analysis that evaluates a broader range of weeds to determine which weeds will benefit and which will not benefit from climate change.

Wilding Pines – Wilding Conifer Spread Model & Wildfire Risk Model

Impacts

Below we discuss potential impacts from modelling wilding conifer spread in the case study AOI.

Modelling assumed full spread of wilding conifers i.e. to all dense (brown) + diffuse (orange) + potential invasion (tan) areas as shown in Figure 14.

Water Yield

Wilding conifer impacts on water yield increases markedly under climate change, both for current and potential invasion scenarios (Fig.24). This is consistent with increased precipitation under climate change, since this increases the potential for interception loss from wilding conifer canopies.

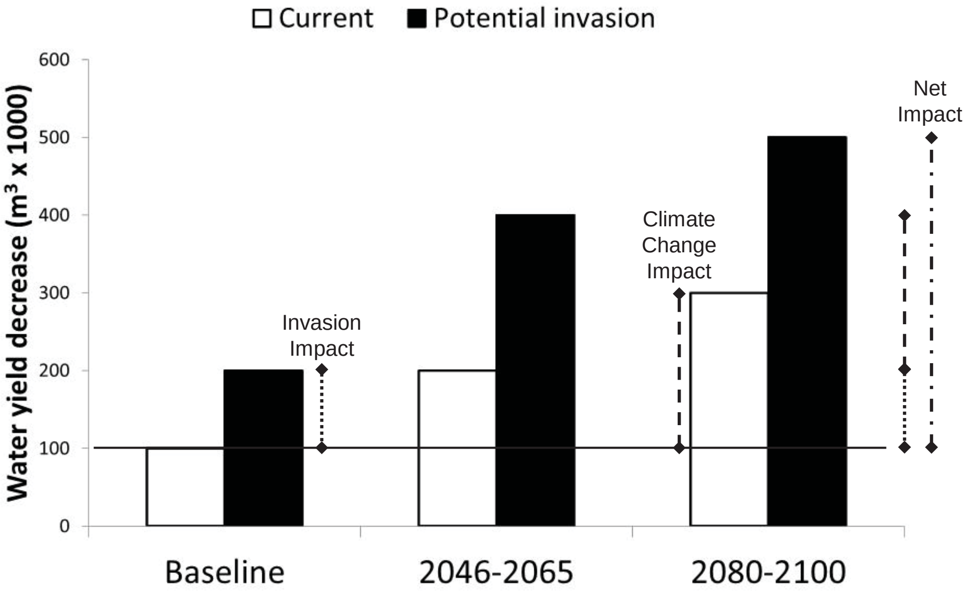


Figure 24: Change in water yield in the Upper Waitaki catchment under RCP8.5. The solid horizontal line indicates current conditions, i.e. current climate based on the recent average from 1986 to 2005 and estimated 2012 distribution of wildlife conifers (Fig. 14). The dotted line indicates impacts from expanded invasion range only compared with the baseline. The dashed line indicates impacts from climate change only compared with the baseline. The dashed+dotted line indicates the impacts from climate change and expanded invasion range operating together.

Wildfire Risk

Wildlife risk increases with climate change and decreases as conifer invasion increases (Fig. 25). The effect of increased invasion is initially greater, as the overall wildlife risk decreases between baseline and 2046–2065. Over time the relative effects reverse, such that net wildfire risk increases only slightly by 2080–2100.

Implications

Climate change will lead to greater impacts of wilding conifers on water yield relative to existing vegetative cover. However, further research is needed to predict how conifer invasion and climate change will interact to influence total water yield and mean or minimum flow rates in the catchment. Wildling conifer expansion also appears to help mitigate the increased risk of wildfire risk resulting from climate change.

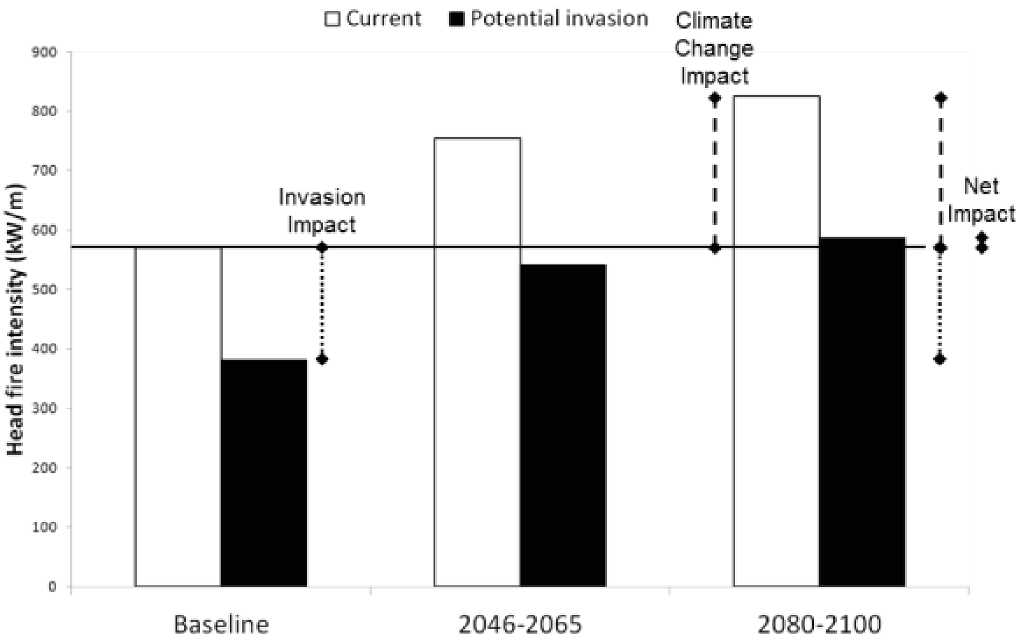


Figure 25: Change in mean head fire intensity (HFI) for the Uplands case study AOI under RCP8.5. The dashed line indicates current conditions i.e. current climate based on the recent average from 1986 to 2005 and estimated 2012 distribution of wildlife conifers (Fig, 14). The dotted line indicates impacts from expanded invasion range only compared with the baseline. The dashed line indicates impacts from climate change only compared with the baseline. The dashed+dotted line indicates the impacts from climate change and expanded invasion range operating together.

Positive impacts are counterbalanced by several negative impacts and uncertainties. The potential invasion scenario modelled for the uplands case study would substantially decrease pastoral land and negatively impact primary production (Fig. 14). Native biodiversity would also be negatively impacted as wilding conifers replace native tussock grasslands and possibly alter the community dynamics and composition of adjacent native forested ecosystems.

Rural Land Use – LURNZ

Impacts

For the LURNZ model, impacts are presented only for the Unspecific Pacific scenario (Fig. 3) combining SSP3 and RCP8.5. LURNZ simulations were carried out at the national level such that outcomes for the uplands case study represent a subset of the national outcomes.

LURNZ used projections of commodity prices generated by the CliMAT-DGE model for RA3 (Rutledge et al 2017). In the Unspecific Pacific scenario, CliMAT-DGE projected that global commodity prices for sheep/beef and forestry increase far above their historic range (Fig. 26).

Compared with 2012, the LURNZ baseline (SSP3-only) modelled an abandonment of ~–20% from sheep/beef to scrub (Fig. 27). Climate-only runs showed consistently little impact on land use when using inputs from either individual NZ-RCM runs or the mean from the ensemble of six NZ-RCM runs (Fig. 28). Under the Unspecific Pacific scenario (SSP3-RCP8.5) showed substantially different trends including an approximately eight-fold increase in forestry, a small increase in dairy, a ~20% decrease in sheep/beef. Scrub and horticulture, which started with a small area, showed little change.

Implications

Overall the rates of land-use change modelled by LURNZ were not as high compared to historical rates.

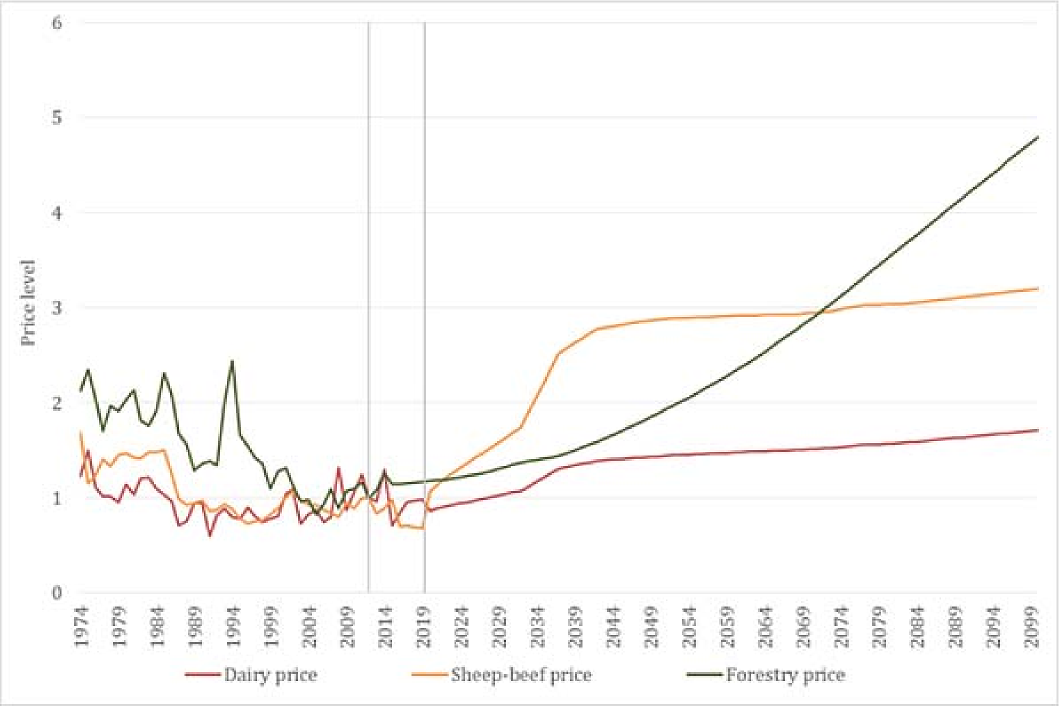


Figure 26 Historic trends and projected future commodity price projections for the Unspecific Pacific scenario (SSP3-RCP8.5-SPA3-SPANZ_A) modelled by CliMAT-DGE that served as inputs for LURNZ modelling.

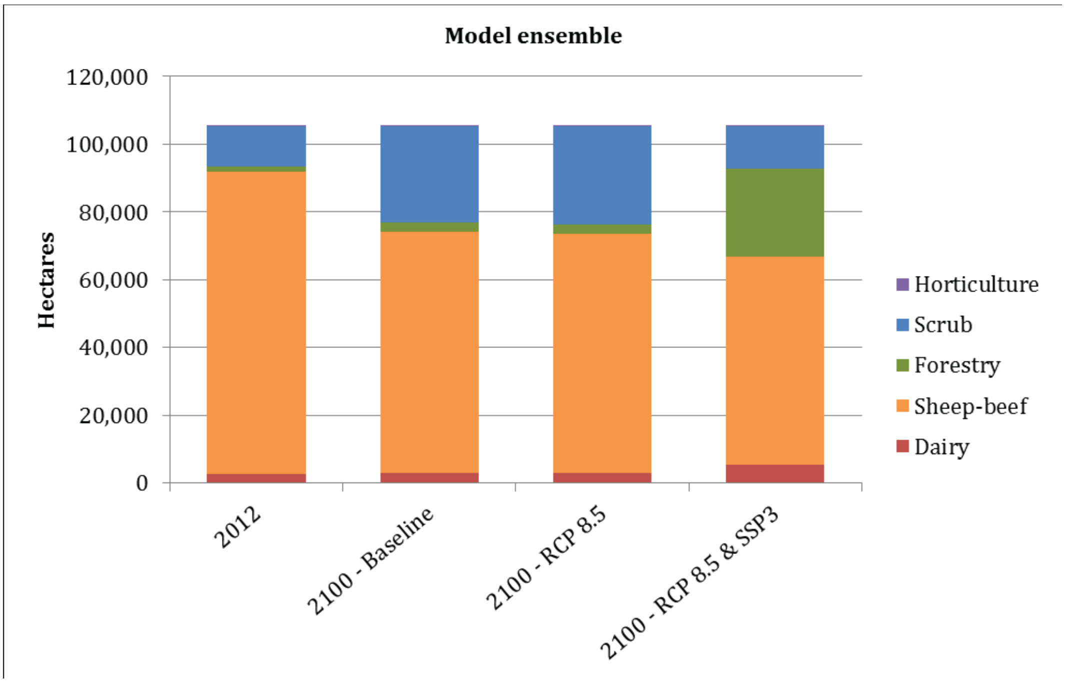


Figure 27 Change in land use area from 2012 to 2100 modelled by LURNZ for baseline (SSP3) only, RCP8.5 only, and the Unspecific Pacific scenario (SSP3 & RCP8.5).

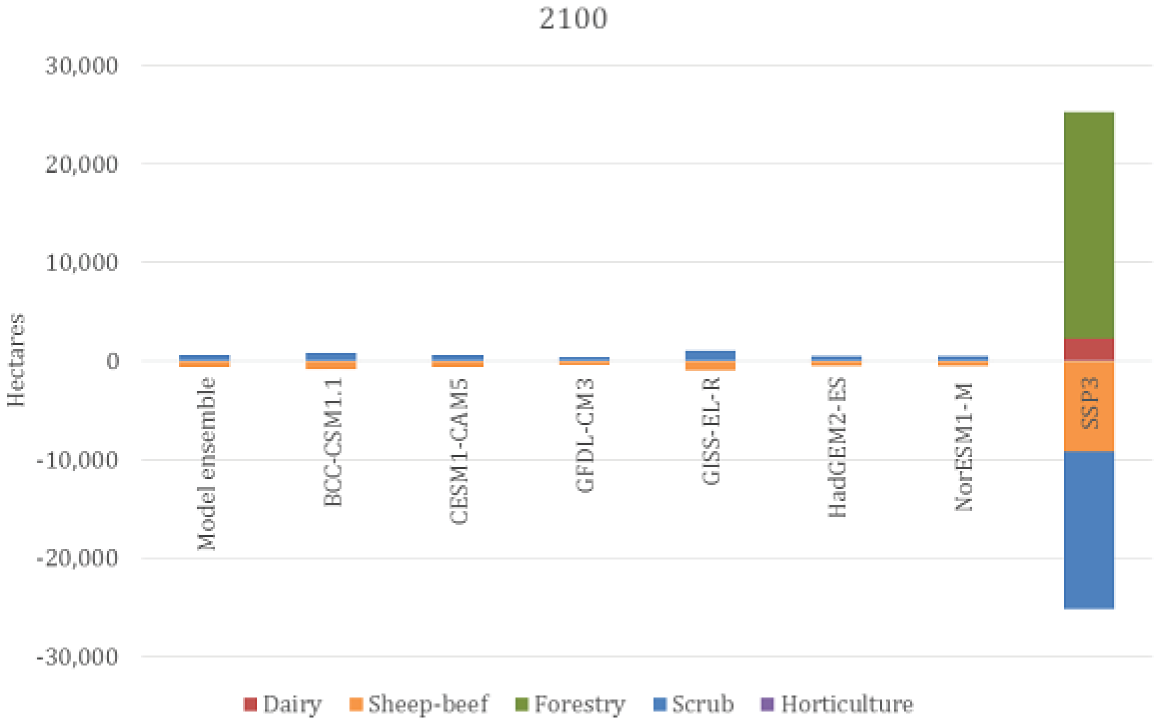


Figure 28 Comparison of modelled change in land use area from 2012 to 2100 based on LURNZ runs considering the ensemble mean of six climate models (left-hand bar), six individual climate models (middle six bars), and the ensemble mean and SSP3 assumptions (right-hand bar).

The largest impacts resulted from assumptions about future changes in commodity prices, whereas climate change showed a consistently smaller impact. Given that commodity prices, especially forestry, increased far above their historic range, the results can be considered plausible but likely highly volatile, given the extreme prices.

The impacts from Unspecific Pacific scenario (SSP3-RCP8.5) imply increasing complexity for water resource management in the upper Waitaki catchment resulting from the interplay of the increase in forestry, the increase in dairy, and the decrease in sheep/beef. Similarly, that interplay would have implications for the catchment's net greenhouse gas emissions. The relatively large increase in forestry area could result in the catchment becoming a local greenhouse gas sink. However the magnitude of that impact would be very minor compared to net greenhouse gas emissions at broader scales, especially given global net Kyoto gas emissions at 2100 for the Unspecific Pacific scenario were at the high end of the global scale, e.g. from 99,701 to 136,248 megatonnes CO_2e per year.

CONCLUSIONS AND SYNTHESIS

This report summarises the results of the CCII Research Aim 2 Uplands Case Study. The case study undertook loosely-coupled systems modelling to better understand the potential impacts and implications of climate change for the economy, environment and society in the upper Waitaki catchment from an integrated perspective. Systems modelling was used to evaluate six scenarios linking global development organised along coupled socioeconomic and representative greenhouse gas concentration pathways with selected aspects of New Zealand development both nationally and sub-nationally, e.g. the upper Waitaki catchment.

Systems modelling operated hierarchically. It used global scenario assumptions, including several key quantitative assumptions for New Zealand, as inputs to a suite of New Zealand-based models, added additional New Zealand-specific assumptions, conditions and considerations, and then modelled resulting future thematic developments both spatially and temporally. Some system model themes depended only on global assumptions or inputs, while other themes depended upon a mixture of inputs globally and/or via feedbacks from other New Zealand themes/models.

Climatically improved climate projections for New Zealand indicate that the regional climate including the case study AOI is likely to become overall warmer, wetter and more variable. For example, the number of hotter days ⩾ 25°C and colder nights ⩽ 0°C will likely increase and decrease, respectively, and annual inflows and discharges from hydroelectric lakes in the AOI will likely increase. Frequency of extreme events such as high rainfall or winds could increase as much as 10–15%, depending on the magnitude of future global greenhouse gas concentrations. While overall the climate will become wetter, changes to seasonal patterns indicate increased potential for more extreme drier periods, especially during summer.

Under changing climatic conditions, hydrological modelling suggests that water management will likely become more challenging and complex and that the scale of the challenge will likely scale with the increasing greenhouse gas concentration and associated radiative forcing. While mean annual flows in the catchment will likely show small average changes over the coming century, mean seasonal flows show more pronounced changes reflecting changes in weather patterns resulting from climate change. Lake inflows, while higher overall as indicated, will likely shift as winter inflows become higher and summer inflows become lower. Changes in the seasonal patterns will affect the timing of storage and delivery of water for a range of uses.

From an agricultural standpoint, pasture productivity modelling projects a net increase in productivity, with likely positive impacts from increasing precipitation and water availability, nitrogen inputs (fertilizer), and CO_2 fertilization effects from higher atmospheric CO_2 concentrations compensating increased temperatures. Pronounced seasonal changes, including larger summer feed gaps and more productive winters, could necessitate adaptation to mitigate shifts in the temporal availability of forage for livestock.

Changing climatic conditions will have mixed implications for weed distribution and management. Suitable areas for many weeds are likely to increase, but some may experience a decrease in suitable areas. Further the changes will vary over time, with some effects felt earlier and some later.

Whether suitable areas for weeds increase or decrease, the corresponding rates of change will depend on a species' individual requirements and therefore must be evaluated on a case-by-case basis. Considering collectively, the shifting patterns of balance and timing among weed species will increase challenges to biodiversity and conservation management by shifting management and control priorities. On balance, the total pressure exerted by weed species on both native biodiversity and primary production is likely to increase.

Wilding pines are particularly problematic. Changing climate will likely significantly increase their potential range within the catchment and lead to further invasion of tussock grasslands that will further reduce the extent and ecological integrity of native ecosystems and agroecosystems. Modelling suggests that the impacts of invasive conifers on water yield relative to existing vegetative cover will increase under climate change.

Impacts and implications of climate change in the catchment will result from both direct and indirect effects of a suite of interacting biophysical, socioeconomic and cultural drivers operating across global, national, regional, and local scales.

In addition to direct impacts causing biophysical changes to native and agroecosystems within the AOI, climate change will also interact in complex ways with socioeconomic developments regionally, nationally, and globally to influence future development. Modelling suggests that impacts from socioeconomic developments may outweigh those from climate change. For example, in one scenario evaluated, global commodity prices for logs increased well beyond their historic range, which drove a substantial increase in forestry land use. Conversely, climate change operating alone via pasture productivity showed little effect on land-use change. Whether that relationship between socioeconomic developments and climate change holds more broadly will require further evaluation.

Although not explicitly modelled, climate change will likely have negative implications for tourism and recreation. For example, reduced snowfall and/or the ability to operate snow-making equipment could over time reduce the net number of days suitable for skiing in the catchment. Also, higher frequency of extreme events could increase risks of damage to important tourism infrastructure such as huts and tracks.

In summary, the uplands case study demonstrated that climate change, when considered in conjunction with broader socioeconomic developments, will likely increase uncertainty and risks and therefore increase challenges to policy, business planning, resource management, and societal resilience into the future. The ability to cope and adapt to changing risk profiles varies among scenarios and depends both on assumed socioeconomic developments as well as the expected degree of climate change.

NEXT STEPS AND RECOMMENDATIONS

Below we outline the next steps and recommendations organised first from an overall perspective and then by the four key themes identified by stakeholders.

- Overall
  - Model and evaluate the full range of scenarios using the current suite of Uplands case study models to understand fully the nature and range of potential impacts and implications. Such a step represents "low hanging fruit" given it would involve the least additional effort.
  - Improve feedbacks among the current suite of models, e.g. link LURNZ, wilding conifer, and TOPNET modelling to explore the dynamic interplay between land-use/land-cover change and hydrology and the potential impacts and implications for water resources management.
- Biodiversity and conservation
  - Consider broader potential impacts and implications of weeds, both individually and collectively, by analysing suitability for a broader suite of high-priority species using the CLIMEX model.
  - Link uplands systems modelling with the modelling of the impacts of mega-masts under climate change undertaken in the RA2 alpine case study (Barron et al. 2016).
- Livelihoods
  - Include modelling that evaluates potential impacts and implications of future climate change to critical tourism and recreation assets in the catchment.
  - Improve TOPNET modelling to better understand the potential complex evolution of hydrological behaviour and the potential impacts and implications for primary production and development via:
    - Consideration of more robust climate trends information for the Southern Alps
    - Explore ways to model hydrological extremes to help inform future impacts and implications for irrigation, flooding, etc.
    - Improved surface water/groundwater interaction (e.g. TopNet-GW)
    - Inter-comparison between model complexity and impacts (surface water, complex integrated, national scale groundwater, conceptual integrated, etc.)
  - Extend BIOME-BGC modelling to include tussock grasslands, irrigated land, and cropland.
- Power generation
  - Enhance modelling of glaciers given their important contribution to seasonal flow patterns
  - Improve collaborations and linkages with the hydroelectric modelling community to improve understanding of potential impacts and implications from a shared and linked socioeconomic and biophysical perspective.
- Wilding Conifers
  - Increase knowledge of the full range of impacts of wilding conifers
  - Improve modelling of wilding conifer dispersal and spread under different management control scenarios
  - Improve WATYIELD results by calibrating wilding conifer water balance parameters to observations

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APPENDIX 1: CCII SCENARIO ELEMENTS & KEY ASSUMPTIONS

Shared Socioeconomic Pathways (SSPs)

Shared Socioeconomic Pathways (SSPs) represent a structured approach to assumptions about future global development organised along two primary axes: challenges to adaptation and challenges to mitigation (van Vuuren & Riahi 2017) (Fig. A1.1). There are five SSPs, each titled with a "road" allusion to provide a sense of their overall nature, composition, and direction of global development or "travel." (O'Neill et al. 2017).

Each SSP includes a broad overall narrative supplemented by more detailed qualitative and quantitative assumptions. The global climate change literature contains more details about the new global SSP architecture (e.g. O'Neill et al. 2017) and implementation of specific SSPs (Calvin et al. 2017; Fricko et al. 2017; Fujimori et al. 2017; Kriegler et al. 2017; van Vuuren et al. 2017).

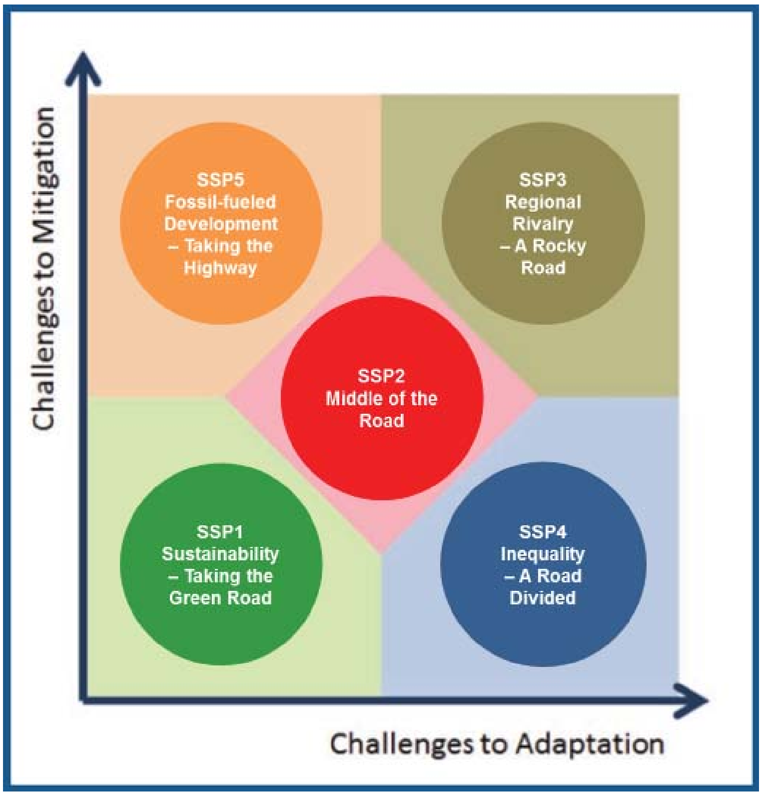

Figure A1.1: Shared Socioeconomic Pathway numbering and titles. Adapted from Ebi et al. (2014), O'Neill et al. (2014), and O'Neill et al. (2017).

Representative Concentration Pathways (RCPs)

Representative Concentration Pathways (RCPs) comprise a set of four standardised pathways of future global greenhouse gas concentrations (van Vuuren et al. 2011). RCPs facilitate comparative exploration of the potential impacts and implications of climate change across the full range of likely future global greenhouse gas emissions and resulting radiative forcing. While called "concentration pathways" the naming convention actually refers to the resulting additional radiative forcing at 2100 in W/m^2 relative to pre-industrial (1850–1900) levels (Fig. A1.2).

The RA1 synthesis report (Tait et al. 2016) contains more information about RCPs and their use in generating the latest set of global climate projections. Global climate projections, in turn, served as the basis for running the New Zealand Regional Climate model that generated the improved climate projections used by RA3: Identifying Feedbacks, Understanding Cumulative Impacts, and Recognising Limits.

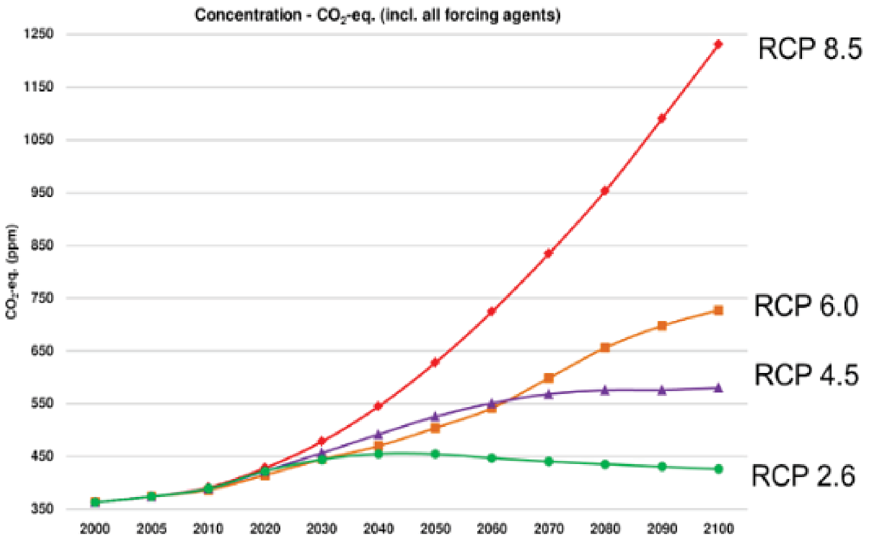

Figure A1.2: Atmospheric CO2-equivalent concentrations (in parts-per-million-by-volume) under the four Representative Concentration Pathways (RCPs) (van Vuuren et al. 2011).

SPAs: Shared Policy Assumptions

Shared Policy Assumptions (SPAs) outline assumptions about development of future global climate policies targeting mitigation of greenhouse gas emissions (Kriegler et al. 2014). SPAs include:

1. *Climate Policy Goals:* emissions reductions targets or different levels of ambition in limiting residual climate damages.

2. *Policy Regimes and Measures:*

   a. *Mitigation:* policy measures could be globally harmonized or regionally differentiated carbon taxes, an international emissions trading scheme with a particular burden sharing mechanism, a mix of different policy instruments ranging from emissions pricing to low carbon technology subsidies to regulatory policies, or a mix of different approaches in different sectors, e.g. including transport policies and schemes to protect tropical forest.

   b. *Adaptation:* the suite of adaptation measures available for implementation (e.g. more efficient irrigation techniques) and level of international support for adaptation in developing countries.

3. *Implementation Limits and Obstacles:* identification of circumstances that would limit policy implementation, such as excluding emissions from some land uses and/regions due to practical constraints.

Shared Policy Assumptions for New Zealand (SPANZs)

The RA5 team developed a new framework for developing New Zealand-focused scenarios nested within global scenarios (Frame & Reisinger 2016). The framework links global, national and local modelling of climate change and its impacts and implications with a range of key quantitative and qualitative indicators. The new framework includes narratives specific to New Zealand's situation that broadly outline developments in the Pacific region and New Zealand's climate and non-climate policy dimensions.

The new framework also introduced Shared Policy Assumptions for New Zealand (SPANZs). SPANZs consist of a structured set of assumptions about how New Zealand climate policies relate to global climate policies as outlined in global SPAs. By default, New Zealand climate policy follows global developments as outlined in the relevant SPA. Most commonly, New Zealand climate policies develop following assumptions that apply to all OECD countries.

The specification of SPANZs allows exploration of scenarios in which New Zealand policies diverge from globally specified trends (Frame & Reisinger 2016). The six SPANZ developed for CCII structured consideration of New Zealand's shared policy assumptions such that New Zealand's approach could lead, remain consistent with, or lag global efforts regarding challenges to mitigation and adaptation (Table A1.1).

Table A1.1: Shared Policy Assumptions for New Zealand (SPANZ)

SHARED POLICY ASSUMPTIONS FOR NEW ZEALAND (SPANZs)		**DOMESTIC APPROACH TO ADAPTATION** (relative to SSP)	
		Short-sighted: Incremental and Focussed on Short Term Gains	**Long-sighted: Strategic and Transformational**
DOMESTIC APPROACH TO MITIGATION (relative to SSP)	**Lags behind global efforts**	**A** NZ lags relative to global mitigation efforts. Adaptation tends to be incremental and reactive on a piecemeal basis, influenced by short-term economic gains and vested interests. This policy stance is dominated by a strong focus to minimise near-term costs and avoid transformational approaches to both mitigation and adaptation. Adherence to international expectations is minimal.	**D** NZ lags relative to global mitigation efforts. A strategic perspective guides adaptation and includes transformational changes where necessary to achieve long-term goals. This policy stance is driven by a perception that NZ has no meaningful role to play in mitigating climate change through mitigation. Instead NZ must focus on securing its own long-term resilience and viability by adapting to inevitable changes.
	Consistent with global efforts	**B** NZ neither leads nor lags global mitigation efforts. Adaptation tends to be incremental and reactive on a piecemeal basis, influenced by short-term economic gains and vested interests. This policy stance is dominated by a strong focus to minimise near-term costs and fundamental transformations in adaptation while complying with international expectations on mitigation.	**E** NZ neither leads nor lags global mitigation efforts. A strategic perspective guides adaptation and includes transformational changes where necessary to achieve long-term goals. This policy stance is dominated by a sense that compliance with international expectations on mitigation is necessary but the real key to long-term prosperity and resilience lies in effective adaptation.
	Leads global efforts	**C** NZ leads global mitigation efforts in terms of ambition and innovation. Adaptation tends to be incremental and reactive on a piecemeal basis, influenced by short-term economic gains and vested interests. This policy stance is dominated by an assumption that strong mitigation is the only solution that protects NZ's international reputation and market access. Adaptation is a 'second-best' response to climate change.	**F** NZ leads global mitigation efforts in terms of ambition and innovation. A strategic perspective guides adaptation and includes transformational changes where necessary to achieve long-term goals. This policy stance reflects an assumption that adapting to change, including through transformation, is key to NZ's well-being. Adaptation as well as mitigation will secure NZ's international reputation and market access as well as moral obligations.

APPENDIX 2: UPLANDS CASE STUDY AOI SUMMARY TABLES

Table A2.1: Number of polygons and spatial statistics of level-1 land use capability (LUC) classes for the Uplands case study AOI. Based on the New Zealand Land Resource Inventory Soils Database (LRIS Portal Soil Database)

LUC Level 1	# of Polygons	Minimum Area (ha)	Maximum Area (ha)	Mean Area(ha)	Total Areas(ha)
3	32	42	3,352	522	16,691
4	104	14	3,546	518	53,859
5	29	51	2,121	400	11,586
6	106	15	123,741	2,472	262,033
7	107	0.11	60,866	2,362	252,713
8	30	3	243,778	9,894	296,829
Lake	5	0.25	19,932	5,967	29,833
River	11	125	22,376	3,791	41,706
Town	2	136	190	163	326

Table A2.2: Number of polygons and area of 2012 land cover for the Uplands case study AOI ordered by area from highest to lowest. Based on the New Zealand Land Resource Inventory Land Cover Database (LRIS Portal Land Cover Database)

Land Cover 2012	# of Polygons	Area (ha)	Area (% of total)
Tall Tussock Grassland	1246	262,236	27.16%
Low Producing Grassland	906	181,871	18.84%
Gravel or Rock	2316	154,750	16.03%
Depleted Grassland	894	114,645	11.87%
High Producing Exotic Grassland	344	56,638	5.87%
Lake or Pond	353	47,474	4.92%
Alpine Grass/Herbfield	931	34,486	3.57%
Permanent Snow and Ice	593	29,684	3.07%
Matagouri or Grey Scrub	1387	19,338	2.00%
Sub Alpine Shrubland	843	17,857	1.85%
Indigenous Forest	457	15,981	1.66%
Exotic Forest	643	8,453	0.88%
Mixed Exotic Shrubland	601	4,882	0.51%
River	66	3,864	0.40%
Herbaceous Freshwater Vegetation	372	3,641	0.38%
Deciduous Hardwoods	543	2,795	0.29%
Manuka and/or Kanuka	174	1,881	0.19%
Short-rotation Cropland	34	1,599	0.17%
Landslide	104	717	0.07%
Gorse and/or Broom	56	648	0.07%
Fernland	89	643	0.07%
Built-up Area (settlement)	52	552	0.06%
Broadleaved Indigenous Hardwoods	40	407	0.04%
Forest – Harvested	15	156	0.02%
Urban Parkland/Open Space	17	143	0.01%
Orchard, Vineyard or Other Perennial Crop	3	122	0.01%
Surface Mine or Dump	28	78	0.01%
Transport Infrastructure	7	32	0.00%
Flaxland	1	2	0.00%

Table A2.3: Number and area of farm types, sub-farm area, and count of livestock for the Uplands case study AOI. Based on AgriBase 2014 (March) licensed for research purposes to Landcare Research by AssureQuality

FARM TYPE			**SUB-FARM AREA**		**CATCHMENT LIVESTOCK BY FARM TYPE**			
Description	Number	Total Catchment Area (ha)	Forestry (ha)	Natural (ha)	Beef Cattle (#)	Dairy Cattle (#)	Deer (#)	Sheep (#)
Arable	1	798	-	-	-	-	-	-
Beef Farming	3	1,641	-	-	730	-	440	27
Dairy Farming	1	2,667	-	-	-	1,100	-	-
Deer Farming	2	44,539	16	-	946	-	1,478	1,730
Forestry	4	34	28	6	-	-	-	-
Fruit Growing	1	49	-	-	-	-	-	-
Grazing	3	7,708	-	-	-	-	-	-
Lifestyle Block	39	129	2	1	16	-	-	56
Natural*	6	208,374	-	5,220	-	-	-	-
New Farm	9	11,655	-	-	-	-	-	-
Not Farmed	9	1,982	-	19	-	-	-	-
Other	3	351	-	-	-	-	-	-
Sheep Farming	33	160,533	370	16	2,505	-	2,026	179,959
Sale Yards	1	7	-	-	-	-	-	-
Sheep and Beef Farming	53	373,749	286	820	17,147	325	10,903	394,761
Tourism	4	15,752	120	-	-	-	-	1
Viticulture	1	27	-	-	-	-	-	-

*Mostly public conservation estate managed by the Department of Conservation